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THE EFFECT OF FLOODING OIL SANDS WITH ALKALINE SOLUTIONS[1]

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ABSTRACT

This paper gives the results of a series of experiments on the flooding of oil sands with ordinary water and solutions of various kinds and concentrations. The most satisfactory results were obtained by the use of dilute alkaline solutions of salts of the weak acids and strong bases, normal sodium carbonate being the most effective of all. Several types of apparatus were employed, including in one series of experiments blocks of Dakota sandstone, which, after being charged with oil under pressure, were subjected to flooding tests.

INTRODUCTION

This paper is based on experimental studies relating to the flooding of oil sands. The laboratory tests were conducted by the writers with the assistance of R. C. Diehl and J. T. Stubbs at the experimental plant of the Colorado School of Mines.

Although the impression generally prevails that there is only one important claimant for the United States patent rights covering the process of flooding oil sands with alkaline solutions, there are in reality several interfering claims in the patent office. An application by the authors of this paper covering the use of all alkaline solutions and based upon laboratory studies extending over a period of several months was filed on June 4, 1925 (Serial No. 34860). The authors' claims are quoted in full as follows:

1. The method of increasing the oil recovery from petroliferous strata which consists in subjecting the material of the strata to the action of aqueous solutions having an alkaline reaction.

[1] Read before the Association at the Dallas meeting, March, 1926. Manuscript received by the editor December 14, 1926.

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2. The method of increasing the oil recovery from petroliferous strata which consists in subjecting the material of the strata to the action of an aqueous alkaline solution.

3. The method of increasing the oil recovery from petroliferous strata which consists in subjecting the material of the strata to the action of an aqueous solution of compounds of the alkali metals.

4. The method of increasing the oil recovery from petroliferous strata which consists in flooding the strata with an aqueous solution of soluble alkaline compounds.

The United States Geological Survey is reported to have applied for a patent on June 10, 1925 (Serial No. 36284). There are several other interfering claims in the patent office covering certain phases of the process. The question of priority in the discovery in the United States has not yet been determined.

The latest development in connection with the patent rights is a serious interference with an English patent issued to Martin Ernest Fylemann on May 26, 1921 (Serial No. 163519).

PURPOSE OF THE STUDY

The object of the study was to determine as far as possible the following facts:

1. The relative efficiency of different solutions as compared with water in releasing oil from oil sands.

2. The concentrations of solutions required to produce the most satisfactory results.

3. The variations in the efficiency of the same solution acting on sands containing different grades and types of petroleum.

4. The relative effect of combinations of solutions of different concentrations as compared with simple solutions of the same concentrations.

5. The effect of variations in temperature of the flooding solutions.

6. The effect of variations in texture and porosity of the sands.

7. The influence of alkaline solutions on the cementing material of certain sandstones.

8. The effect of flooding on the concentration of alkaline solutions.

9. The effect of flooding with water after soaking the oil sands with alkaline solutions.

10. The effect of alkaline flooding solutions upon the oil.

PLAN OF THE INVESTIGATION

In the search for the most satisfactory solutions for the flooding of oil sands, the investigation was divided into three steps. In the first, a group of qualitative experiments was undertaken in order to determine the relative efficiency of different solutions in relasing the oil films from sand grains. In the second, a series of small-scale flooding experiments was made to determine the effectiveness of solutions quantitatively, the number of solutions to be employed having been reduced considerably by the results of the previous tests. The third step involved quantitative determinations on a larger scale, the number of solutions again being reduced by elimination from the preceding trials.

Subsequent to the determination of the most effective solutions and their con-

centrations for flooding practice many further tests were made bearing on other phases of the flooding problem.

PRELIMINARY QUALITATIVE EXPERIMENTS

Oil sample bottles of a capacity of 8 ounces were one-third filled with sand of medium texture of 36 per cent porosity one-half saturated with Salt Creek crude (38.8° A.P.I.). After the oil sand was saturated by, and covered with, about 2 inches of solutions of different types and concentrations the bottles were corked and permitted to stand without agitation. In choosing different compounds to be employed in this work an effort was made to select those which would be representative of every possible type, namely, salts of weak acids and strong bases, salts of strong acids and strong bases, salts of weak acids and weak bases, acid salts, weak and strong acids both organic and inorganic, and weak and strong bases. Altogether, nearly two hundred different compounds and combinations of compounds were employed. In the case of the more active solutions the oil was slowly released from the oil sand and rose to the surface as small droplets which coalesced to form a film. In this connection it is interesting to note that after the first two weeks no further action of importance was noted in most of the bottles, even though they were allowed to stand for more than a year and a half. These preliminary tests indicated that salts of strong bases and weak acids were superior. Of all the solutions used, those of sodium carbonate, sodium bicarbonate, potassium carbonate, lithium carbonate, ammonium carbonate, sodium silicate, sodium borate, sodium oleate, ammonium oxalate, sodium cyanide, sodium sulphite, sodium bisulphite, sodium nitrite, and sodium xanthate were the most successful. The relative effect of these varied, however, with the different grades

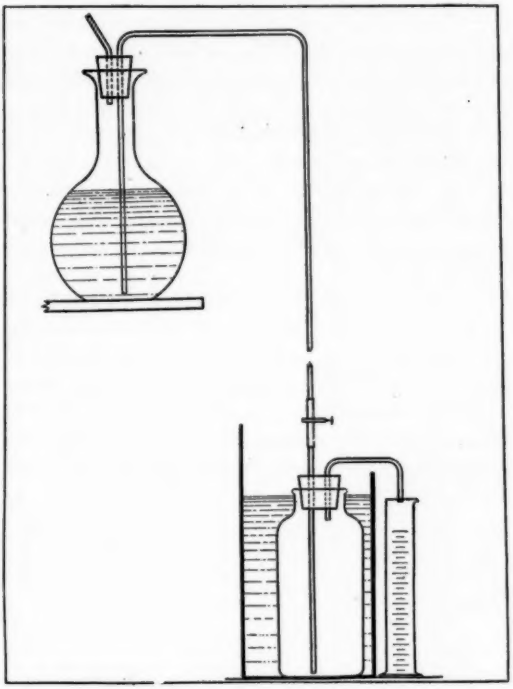

FIG. 1

and types of oil employed. Everything considered, sodium carbonate was conceded to be the most satisfactory compound of all for flooding operations.

Considerable attention was given to sodium chloride in order to determine whether it, either alone or in combination with any of the above compounds or with lime water, would aid in the extraction of oil under any condition of concentration. It was found to be very ineffective alone and of doubtful value in combination.

QUANTITATIVE TESTS WITH BOTTLES

GENERAL STATEMENT

In the more detailed tests which followed it was found necessary not only to control the temperature, but to conduct several experiments simultaneously under identical conditions of temperature and pressure in order to secure comparative quantitative data. A battery of six bottles with a capacity of 122 cc. each was used. The details of the apparatus are illustrated by the accompanying diagram (Fig. 1).

The rate of flow of the solutions was regulated by pinch cocks placed on the rubber outlet tubes, a 4-foot hydrostatic head, equivalent to about 1.75 pounds per square inch, being maintained. The temperature was controlled by means of a water bath.

EFFECT OF CONCENTRATION

In one group of quantitative experiments the effect of the concentration of the solutions upon the efficiency of flooding was studied. Table I gives the data obtained by flooding a −20-mesh sand with a porosity of about 36 per cent, one-half of the pore space being saturated with Salt Creek crude (38.8° A.P.I.), by normal sodium carbonate solutions varying in concentration from 1 to 10 per cent, 130 cc. of flooding solution being used for each bottle:

TABLE I

Percentage of Concentration of Solution....	10	5	2	1	0.5	0.2	0.1
Percentage of Oil Recovered from Sand....	44.5	50.0	55.5	55.5	27.8	22.2	11.1

These results were obtained at a temperature of 18° C., which is considerably lower than that found at the bottom of most oil wells. It is interesting to note that at this temperature the yield of oil fell off rapidly for concentrations lower than 1 per cent and that it also decreased, though not to the same degree, for concentrations greater than 2 per cent. At temperatures between 42° and 45°C. the influence of the higher concentration was not so great, the 10 per cent solution bringing over as much oil as the 1 per cent solution.

EFFECT OF GRADE OF OIL

In this test three grades of oil were employed, namely, Osage, Wyoming crude (41° A.P.I.), Salt Creek crude (36° A.P.I.), and Poison Spider crude (13° A.P.I.). The sands were flooded at 20° C. with a 1 per cent solution of normal sodium car-

bonate, 130 cc. of solution being passed through each bottle filled with sand one-half saturated with oil. The recovery was 45.5 per cent of the available oil from the sand containing Osage oil, 40 per cent from the sand bearing Salt Creek oil, and none from the sand with Poison Spider crude. In the case of the Poison Spider test, it was noted that the oil was thoroughly loosened from the sand, but its viscosity was too great for it to be forced out of the bottle, at the low pressure employed. From these results it may be concluded that the gravity of the oil is a very important factor to be considered in flooding.

INFLUENCE OF TEXTURE AND MINERALOGIC CHARACTER OF THE SAND

In order to determine the effect of the texture and mineral composition of the sand on the yield of oil, sands of the following meshes and types were employed:

−10-mesh; pure quartz, well-rounded grains.
−10-mesh; quartz, 60 per cent, mica, 35 per cent, other minerals, 5 per cent.
−20-mesh; quartz, 95 per cent.
−40-mesh; quartz, 95 per cent.
−60-mesh; quartz, 95 per cent.
−60-mesh; quartz, 60 per cent, silt and clay, 40 per cent.
−80-mesh; quartz, 95 per cent.

These sands were flooded under varying conditions, and the results led to the following conclusions:

1. The finer the sand, the greater the recovery. This is to be expected, since the finer the sand the greater the surface from which the oil may be driven, and also the greater the effect of the capillary force, since the surface tension of the sodium carbonate solution is considerably greater than that of the oil.

2. A pure quartz sand is better adapted to flooding than a heterogenous sand. Mica flakes tend to orient themselves so as to obstruct the passage of the fluids, apparently following the geologic law according to which crystals orient themselves with their long axes perpendicular to the greatest pressure. Fine silt tends to obstruct the pore spaces and to inhibit the flow of fluids. Clays in the sand also tend to cause emulsification.

INFLUENCE OF TEMPERATURE

In order to secure quantitative data relative to the effect of temperature upon the efficiency of recovery, tests were made with sands ranging from 20- to 60-mesh, one-half saturated with different types of oil. The temperatures employed ranged from 15° to 55° C. In all cases it was found that the recovery varied directly with the temperature, using a constant volume of solution of the same composition and concentration.

It is interesting to note that, disregarding the volume of the solution employed, the ultimate recovery in case of the lighter oils was essentially the same in each instance.

Poison Spider crude, which could not be recovered at low temperatures, was easily flooded from the sand at temperatures ranging from 40° to 55° C.

DEGREE OF RECOVERY

In this operation it was endeavored to determine the degree of recovery possible by flooding oil sands with a 1 per cent solution of normal sodium carbonate. Using a medium-textured sand of 36 per cent porosity with the degree of saturation of high-grade Wyoming crude varying from 50 to 100 per cent, it was found that the maximum recovery was 88 per cent of the oil in the sand. To attain this, continuous flooding over a period of 36 hours was necessary. Table II throws some light on this phase of flooding.

TABLE II

Time in Hours	Percentage of Oil Recovered	Ratio of Recovered Oil to Solution
1	55	1:10
2	65	1:25
5	78	1:125
10	85	1:500
36	88	1:2,000

An increase of temperature at the end of 36 hours failed to bring over any additional oil. When the sand was removed, part of the remaining oil appeared to have been loosened from the sand grains, but was apparently trapped under the shoulders of the bottles.

EFFECTIVENESS OF WEAK ACID SOLUTIONS

Inasmuch as it has been reported that weak acids as well as solutions of the salts of the weak acids and strong bases are effective in releasing oil from sand grains, it was decided to make quantitative comparisons. In the following table the yields of oil obtained with extremely dilute acid solutions (1 to 6,000) are compared with those obtained with water and with a 1 per cent sodium carbonate solution. All the tests were made at room temperature.

Solution Used	Percentage of Oil Recovered
Formic acid	20
Propionic acid	20
Butyric acid	20
Sulfuric acid	10
Cresylic acid	25
Water	25
1 per cent sodium carbonate	67

Solutions of other acids, including acetic acid, of many concentrations were also employed, with unsatisfactory results. It is the authors' experience that acid solutions, both organic and inorganic, either dilute or concentrated, are ineffective in releasing oil from sand grains.

INCLINED-TUBE TESTS

Pyrex glass tubes, 12 inches long and $\frac{3}{4}$ inch in internal diameter, with a capacity of 120 cc., were used in another series of experiments. These were sealed at each end with rubber stoppers through which the inlet and outlet tubes led, and were equipped with water jackets to regulate the temperature (Fig. 2). The solutions were siphoned over from flasks, a hydrostatic head of 4 feet being maintained.

INFLUENCE OF GEOLOGICAL STRUCTURE

This apparatus could be used advantageously to study the influence of geological structure upon flooding operations. The tubes were placed at different angles to the horizontal, in some cases the discharging ends for the fluids being higher, and in other cases lower, than the charging ends. Anticlinal and synclinal positions were also simulated by using two tubes together, as indicated in the accompanying diagrams. Figure 3 illustrates an anticlinal effect, and Figure 4, a synclinal effect.

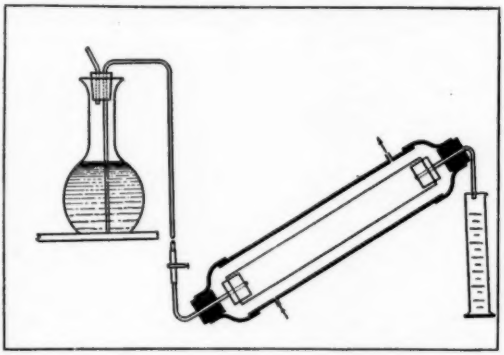

FIG. 2

It was found that the lower the intake with respect to the outlet, the better the recovery, the yield being largest when the solution entered at the bottom of vertical tubes.

Furthermore, the introduction of the flooding solutions on the flanks of a model anticline (Fig. 3, *B*) gave better results than when the solutions were introduced at the crest of the anticline (Fig. 3, *A*). This phenomenon is easily explained on the basis of differences in specific gravity between the flooding solutions and the oil.

EFFECT OF RATE OF FLOODING

In order to determine the effect of the rate of flooding on the recovery, several kinds of oil were used in conjunction with various types of sand, the time rate of flooding with equal amounts of solution varying from 30 minutes to 36 hours. The results of these tests were not entirely successful. The conditions governing the most advantageous rate of flooding apparently follow no set rules, and are influenced by a great many factors, such as the porosity of the sand, the texture of the sand, the type of oil, and the temperature.

Other conditions being equal, it is probable that the high-grade oils may be flooded from a sand more rapidly than the heavy, viscous oils, owing to the greater tendency of the solutions to by-pass the heavy oils.

STEEL-PIPE TESTS

Steel pipes 3 inches in diameter and 3½ feet in length were fitted with steel screw caps in which wire screens had been sealed with "Smooth On" cement. The capacity of each pipe was about 3,500 cc. The charge of sand partly saturated with oil was thoroughly tamped into the pipes and was further compacted by filling the caps with sand and screwing them on with a large wrench. The pipes were immersed in a water bath the temperature of which was regulated by steam (Fig. 5). The solution, after being charged into a tank of a capacity of about 30 liters, was placed under an air pressure ranging from 30 to 50 pounds. A forced circulation was then set up through the oil sand in the steel pipes, the solution entering at the base of the apparatus and discharging at the top through separatory funnels in which the oil and solution were trapped. The proportions of each were then measured in a graduated flask. This apparatus, being on a much larger scale and permitting a higher degree of compaction of the sands, simulated more closely conditions existing in nature.

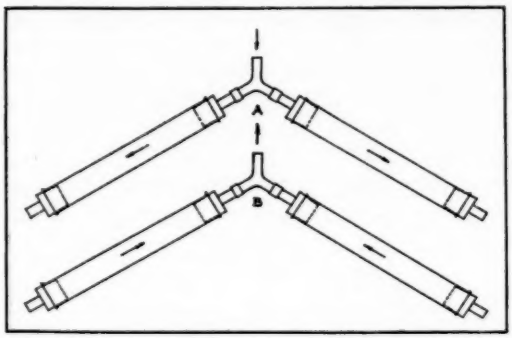

FIG. 3

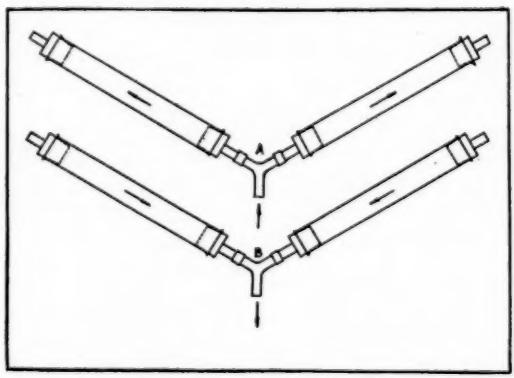

FIG. 4

This equipment was used to confirm and check the results obtained in the small-scale experiments. In general the results were very similar to those secured with the smaller apparatus.

DAKOTA-SANDSTONE-BLOCK TESTS

In all of the earlier experimental work, the tests were made with unconsolidated sands packed into different types of containers. It was deemed advisable, there-

fore, to observe the effect of alkaline solutions upon blocks of consolidated sandstone saturated with oil by artificial means.

Rounded blocks of Dakota sandstone with siliceous cement, ranging from 4 to 16 inches in diameter and with an average porosity of about 23 per cent, were employed. Holes ½ inch in diameter with the bottoms slightly enlarged were drilled into these, and steel pipes cemented into the upper part of the openings with "Smooth On" cement. Crude oil was then forced into the blocks by means of air pressure, using the apparatus illustrated in Figure 6.

In one of the earlier experiments the relative efficiency of water as compared to a 1 per cent sodium carbonate solution in flooding sandstone thoroughly satu-

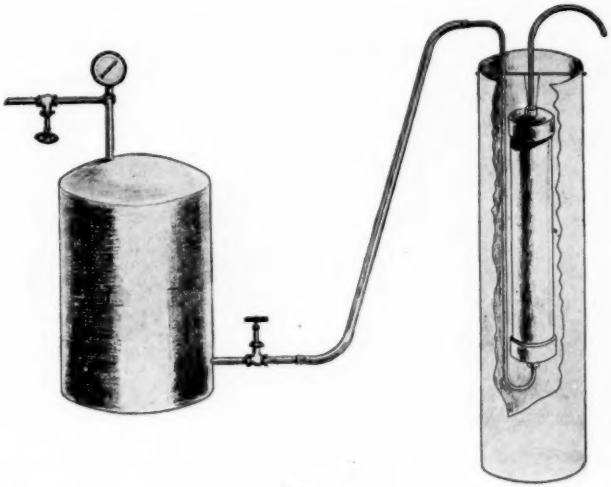

FIG. 5

rated with oil was studied. Two blocks of like size were flooded under similar conditions with duplicate apparatus (Fig. 6), one with water and the other with sodium carbonate solution. It was found that over a given period of time the sodium carbonate solution was six times as effective as the water, 53 per cent of the oil in the block being recovered with the sodium carbonate solution. This experiment was repeated several times, and each time the block flooded with sodium carbonate solution disintegrated before the oil recovery was complete, whereas the water had no such effect. It was assumed that this phenomenon resulted from the action of the alkaline solution upon the siliceous cement of the rock.

In order to demonstrate this, however, two sandstone blocks containing no oil were flooded, one with a dilute sodium carbonate solution and the other with distilled water, over a period of 72 hours. Following the flooding, samples of the original fluids and of the discharged flooding fluids were subjected to an electro-

metric titration. The original sodium carbonate solution contained 8.80 grams per liter of sodium carbonate, whereas the discharged solution contained only 8.05 grams per liter. The water showed no change. This result would indicate that a chemical reaction between the sodium carbonate and cementing material of the sandstone had occurred. This is interesting in that it indicates that if oil sand with siliceous cement were flooded with a sodium carbonate solution the cementing material would be attacked, causing disintegration of the rock. The effect of such a disintegration upon the oil recovery should be investigated.

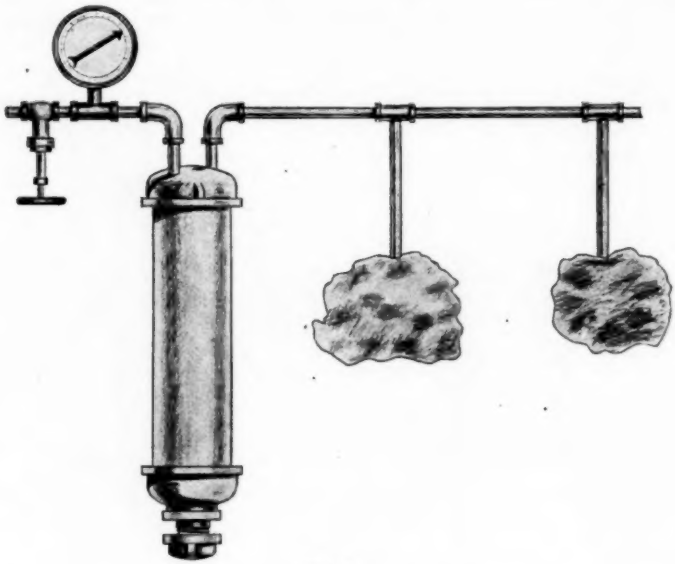

FIG. 6

EFFECT OF FLOODING ON ALKALINE SOLUTIONS

From the results obtained, it was considered important to determine whether the sodium carbonate content of a solution of this salt would be depleted in flooding an ordinary unconsolidated quartz sand 50 per cent saturated with crude oil. The fresh sodium carbonate solution was first titrated against standard sulphuric acid, and its normality found to be 0.189, whereas the discharged solution showed a normality of only 0.182. It is probable that the concentration of the solution was decreased in the work of displacing the oil from the quartz grains as well as by slight reaction with the grains themselves. It would be interesting to compare the effects on the solutions during the flooding of calcareous oil sands with those obtained by flooding siliceous oil sands.

EFFECT OF PRELIMINARY SOAKING OF OIL SANDS

In connection with the flooding experiments some preliminary tests were made to determine the feasibility of first soaking oil sands for a short time with dilute solutions of sodium carbonate in order to release the oil films from the sand grains and then flooding them with ordinary water to drive out the oil. In general, the results obtained were very satisfactory, although the oil was not freed from the sand to the same degree as by continuous flooding with sodium carbonate solutions.

EFFECT OF FLOODING UPON PROPERTIES OF THE OIL

The oil recovered from an oil sand by flooding apparently undergoes no changes in character except those induced by evaporation losses. These are, of course, greater for the high-grade crudes than for the low-grade types. Allowing for the losses, the distillation curves remain the same for the displaced oils as for the original crudes used in the experiments.

The recovered oils are not emulsified to an appreciable extent except when soaps are added to the flooding solutions or when clay particles exist in the oil sands. In general there appears to be less danger of emulsification in flooding the asphalt base crudes than in flooding the high-grade oils, except in cases where emulsifying agents already exist in the low-grade crudes.

SUMMARY AND CONCLUSIONS

SOLUTIONS EMPLOYED

The solutions employed in the flooding experiments were as follows: (1) ordinary tap water; (2) solutions of neutral salts; (3) solutions of acid salts; (4) strong acids; (5) weak acids; (6) concentrated alkaline solutions; (7) dilute solutions of the hydroxides of the alkalies; (8) dilute alkaline solutions of the salts of the weak acids and the alkalies, such as sodium carbonate, sodium bicarbonate, borax, water glass, sodium oleate, and many others.

With the lighter and better-grade paraffin-base oils, ordinary water flooding gives a fairly high recovery until the water becomes contaminated with oil. But in the case of the asphaltic-base crudes, ordinary water flooding is very ineffective except at higher temperatures. Apparently the asphalts and unsaturates have a greater adhesion for sand grains than the paraffins.

The solutions of neutral salts of variable concentration are ineffective, some of them even less effective than ordinary water.

Strong acids act as deterrents in every case. Weak acids with concentrations ranging as low as 1 to 6,000 are no more effective than ordinary water.

Concentrated solutions of the hydroxides of the alkalies exert little effect, but dilute solutions of these hydroxides, both alone and in combination with certain other compounds, tend to increase the yield of oil over that obtained by ordinary water.

Dilute solutions of salts of a strong base and a weak acid were the most effec-

tive of all. For most types of crude oil, sodium carbonate solutions were found to be the most satisfactory from all points of view. Impure sodium carbonate, or common washing soda, is as effective as the chemically pure salt. The former is cheap, easily obtained, safe to handle, and is readily soluble in water. A 1 per cent solution by weight appears to be the ideal concentration. A decrease in concentration below 1 per cent rapidly diminishes the effectiveness of the solution except at higher temperatures. If a field has already been flooded with water or if bottom- or edge-water is likely to creep in, the concentration of the solution should be increased proportionately to allow for this.

FACTORS INFLUENCING RECOVERY

The recovery obtained by flooding oil sands with dilute solutions of sodium carbonate is variable and depends upon the following factors:

1. The degree of saturation of the sand with oil.
2. The concentration of the solution employed. In general, low concentrations down to 1 per cent are more effective than higher concentrations.
3. The temperature. Higher temperatures are more important for lower-grade oils than for high-grade oils.
4. The amount of solution passed through the sand. The yield of oil is much higher in the early stages of flooding than in the later stages.
5. The type of oil in the sand.
6. The texture, porosity, and continuity of openings of the sand.
7. The continuity and uniformity of the oil sand.
8. The inclination of the oil sand.
9. The kind and amount of cementing material in the oil sand.

The total recovery of oil in the experiments ranged from 50 to 90 per cent, using sands 50 per cent saturated with crude oil. The higher recovery, however, was obtained only after a large volume of solution had been passed through the sand. We are of the opinion that in actual field practice the flooding of oil sands under favorable conditions will not result in a recovery of more than 75 to 80 per cent of their oil content prior to the attainment of the economic limit of flooding operations.

It is generally supposed that the less viscous the oil, the more readily it may be driven out of a sand by flooding solutions. This, however, is not always true. With certain combinations of alkaline compounds in dilute solutions the writers have been able to secure very satisfactory recoveries of extremely low-grade crudes at room temperature.

IMPORTANCE OF STUDY OF FIELD CONDITIONS

Our experience in an experimental way leads us to emphasize the advisability of a careful investigation of local conditions prior to the inception of soda-ash flooding operations. Among the factors which should be considered are:

1. The geological structure of the area and the position of the lease on the

structure. This will govern the location of the intake wells and the oil recovery wells. In areas of well-defined dips the oil should be driven up-dip.

2. The sand conditions, such as the continuity of the sand, its thickness, its texture, its porosity, the amount of clay impurities, and the nature of the cementing material.

3. The type of oil in the sand.

4. The composition of the water, if any, already in the sand.

5. The hydrostatic head of the edge-water. In some fields it may be possible to introduce soda ash into encroaching edge-water with satisfactory results.

If possible, samples of the sand and of the oil, as well as of the water, from an individual oil field should be examined and experimented with in the laboratory prior to the planning of a flooding program for this particular field. The proper compounds or combinations of compounds and the concentration best adapted to local conditions can then be scientifically determined. Under haphazard conditions of flooding failure is to be anticipated in certain fields.

APPLICATION TO MINING METHODS

With reference to some of the proposed methods of mining oil sands, attention should be called to the fact that under certain conditions flooding with alkaline solutions might be carried on systematically and effectively from underground workings. A larger recovery would be expected from such a treatment of the oil sands than from ordinary flooding from the surface, both because of closer spacing of the intake centers and of more effective drainage and recovery methods.

THE STRATIGRAPHY AND OIL PROSPECTS OF ALBERTA, CANADA[1]

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ABSTRACT

The Paleozoic formations range in age from Cambrian to Permian. The Triassic is known only in the Banff region and on west Peace River. All the Jurassic, approximately Middle and Upper, is embraced in the Fernie formation which outcrops along the foothills in western Alberta. Cretaceous strata cover most of Alberta and are variable in lithology and origin, but correlation is possible from the studies of floras and faunas. Within the foothills several areas are being tested for oil and gas and intensive development is taking place in Turner Valley. Turner Valley is a sharp fold with a deep syncline in the center of the anticlinal structure. The Vulcan well has found production in the syncline more than 1,400 feet deeper than Royalite No. 4 well, which is producing about 500 barrels a day of 73° Bé naphtha from a horizon tentatively considered as late Paleozoic. A transverse normal fault cuts off the northern end of Turner Valley, and north of the fault the structure is a westward-dipping fault block. One well is being drilled on this fault block, and since there are many similar structures in the foothills, this well is of special importance in oil developments. Other structures are being drilled in the foothills and conditions appear favorable for oil production. On the plains east of the foothills several folds are producing gas and oil, and tests are now being made of prospective productive horizons on favorable structures.

PHYSIOGRAPHY

Western Canada, including the provinces of Manitoba, Saskatchewan, and Alberta (Fig. 1), comprises three physiographic subdivisions: (1) the plains, a broad area extending from the western or southwestern edge of the Precambrian shield in eastern Manitoba and all of southern and central Saskatchewan, to the foothills of western Alberta, (2) the foothills of southern Alberta, a relatively narrow belt not more than 20 miles wide which merges into the plains on the east, and (3) the mountains on the west.

The plains have, commonly, a northeasterly slope, but in reality are composed in southern Canada of three steppes, or prairie levels, separated by two eastward-facing escarpments. The first steppe, or lowest level, comprises the Manitoba Lowlands, having an average elevation of about 800 feet above sea-level and draining through the Precambrian shield to Hudson Bay. It is underlain by Paleozoic rocks of Ordovician, Silurian, and Devonian ages. It is separated from the second steppe by an escarpment which forms the eastern edge of the Cretaceous rocks of the western plains area. Drainage channels from the second to the first level divide the escarpment into several plateau areas, known as Pembina, Duck, Riding, Porcupine, and Pasquia hills, the summits of which rise from 500 to 1,000 feet higher than the Manitoba Lowlands. The second steppe slopes upward toward the south-

[1] Read before the Association, by G. S. Hume at the New York meeting, November 16, 1926. Published with the permission of the Director, Geological Survey of Canada.

[2] Introduced by O. B. Hopkins.

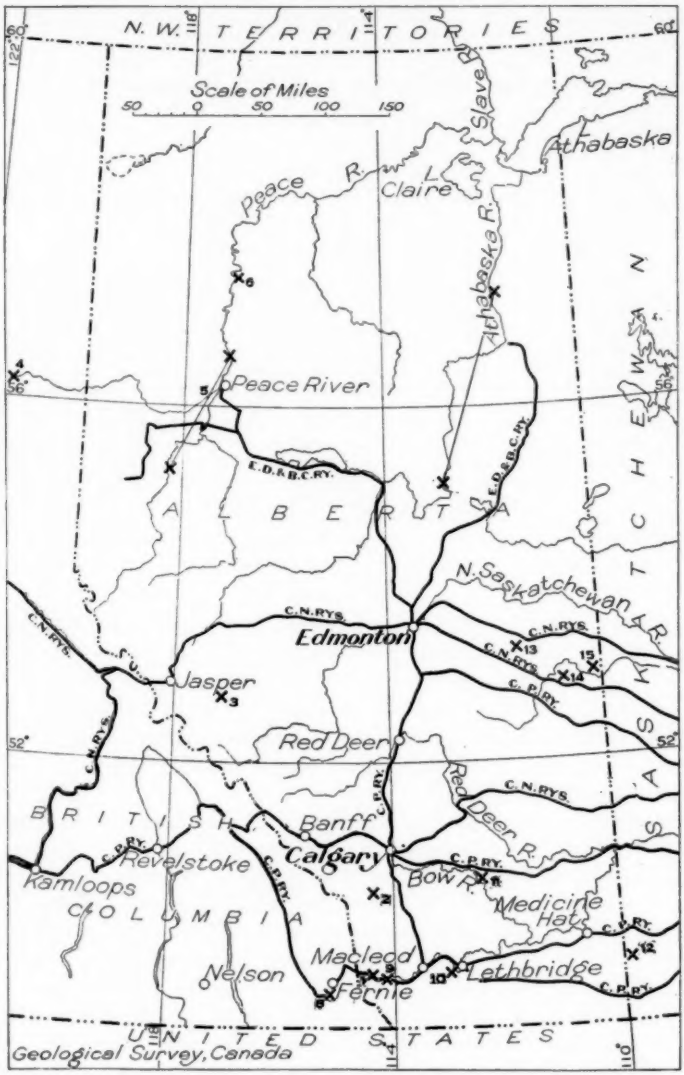

FIG. 1.—Map of Alberta, Canada. Index to localities shown on map. (1) Blairmore-South-fork area; (2) Turner Valley area; (3) Mountain Park area; (4) West Peace River section; (5) Lower Smoky–Lower Peace River section; (6) North Peace River section; (7) Lower Athabaska River section; (8) Morissey area, B.C.; (9) disturbed-belt area, Crowsnest River; (10) Oldman River section east and west of Lethbridge; (11) Bow River section; (12) Cypress Hills area; (13) Viking gas field; (14) Wainwright–Battle River oil field; (15) Ribstone-Blackfoot area.

west into the third steppe, which continues to the foothills of the mountains rising from an elevation less than 1,500 feet to more than 4,000 feet. In the northern part of Alberta and Saskatchewan there is no break between the second and third prairie steppes, but in the south the two are separated by the eastward-facing escarpment of the Missouri couteau which in Canada forms the eastern boundary of the Wood Mountain–Willowbunch plateau. This represents a rise from 200 to 500 feet higher than the second steppe, but this is not continued without break to the foothills, there being a descent on the western side of Wood Mountain equal to the rise on the eastern side. To the west, partly in Saskatchewan and partly in Alberta, lie the Cypress Hills, a plateau several hundred feet above the prairie level and, like Wood Mountain, considered to represent an erosion remnant within the third prairie steppe.

The plains on the west gradually merge into the foothills without marked break, although in southern Alberta Stewart has considered the Porcupine hills as occupying a position between the foothills and the plains. The foothills are in general parallel ridges with a northwest strike following closely the strike of the mountains farther west. They are, for the most part, however, sharply differentiated from the mountains, lithologically, as the mountains are chiefly composed of limestones and quartzites of Paleozoic age, with the summits free from vegetation, whereas the foothills are composed mostly of less resistant sandstones and shales of Mesozoic age, and outcrops are to a large extent obscured by vegetation.

STRATIGRAPHY

F. H. MC LEARN

PALEOZOIC

The Paleozoic of Alberta outcrops along its western border in the Rocky Mountains and Front Ranges. It has received the most attention at Banff, where it has been examined by McConnell,[1] Dowling,[2] Allan,[3] Kindle,[4] Shimer,[5] and Warren. Kindle, who has seen the Paleozoic in several localities, states[6] that the late Paleozoic formations exhibit considerable uniformity north and south, so that in a general way the Banff section applies to most of western Alberta within the Rocky Mountain belt. Kindle's[7] section is as follows:

Rocky Mountain quartzite	Pennsylvanian
Rundle limestone (Upper Banff limestone)	Pennsylvanian
Banff shale (Lower Banff shale)	Mississippian
Banff limestone and dolomite (Lower Banff limestone; Intermediate limestone)	Devonian
Sawback limestone	Cambrian

[1] R. G. McConnell, *Geological Survey of Canada*, Annual Report, new series, Vol. 2 (1886), pp. 1D to 41D (1887).

[2] D. B. Dowling, "Cascade Coal Basin," *Geological Survey of Canada* (1907).

[3] J. A. Allan, *Geological Survey of Canada*, Sum. Report (1912), pp. 165–76.

[4] E. M. Kindle, *Pan-American Geologist*, Vol. 42 (1924), pp. 113–24.

[5] H. W. Shimer, *Geological Survey of Canada*, Bull. 42 (1926), p. 89, pls.

[6] E. M. Kindle, Personal communication.

[7] *Pan-American Geologist*, Vol. 42 (1924), p. 115.

Shimer[1] makes some changes. He places the Rocky Mountain quartzite in the Permian. He gives the name of Minnewanka formation to the Banff limestone and dolomite and adds Walcott's[2] formation, the Ghost River. Shimer's section is as follows:

Rocky Mountain quartzite.....Permian
Rundle formation (Upper Banff limestone).....Pennsylvanian and Mississippian
Banff formation (Lower Banff shale).....Mississippian
Minnewanka formation { Lower Banff limestone / Intermediate limestone } Devonian
Ghost River formation.....Age (?)
Cathedral formation...Cambrian

Warren's report has not yet been published.

Paleozoic rocks, including Devonian, are also found on the lower parts of Peace and Athabaska rivers.

TRIASSIC

Not much is known of the Triassic in this part of Canada. In the Banff section the Spray River formation (Upper Banff shale) is of Triassic age.[3] It consists of shale, limestone, and sandstone, and contains a marine fauna. In the western Peace River area the thick Schooler Creek formation is Triassic. It consists of limestone and calcareous quartzite and contains upper Triassic faunas from Karnic to Noric, the lowest fauna being the *Dawsonites* fauna and the highest the *Pseudomonotis subcircularis* fauna.[4]

JURASSIC

The Jurassic of western Alberta and eastern British Columbia is for the most part embraced in the Fernie formation, which extends on both sides of the Rocky Mountains from the international border to Athabaska River at least, and may be represented by the Pine River shales[5] on Pine River in the Peace River district. It is in most places a dark shale, but sandstone and calcareous bands are also present. It contains in different localities different faunas, which range in age from about basal Middle Jurassic to middle Upper Jurassic.[6] The Jurassic has not been found on the lower Peace and lower Athabaska rivers.

CRETACEOUS

Cretaceous strata cover the greater part of Alberta and differ considerably in lithology and fauna and flora. Not all of the Cretaceous is well understood; in-

[1] *Geological Survey of Canada*, Bull. 42, Contrib. Can. Pal., p. 3.

[2] C. D. Walcott, *Smithsonian Miscellaneous Collections*, Vol. 67 (1923), pp. 463–64.

[3] E. M. Kindle, in L. Lambe, *Trans. Roy. Soc. of Canada*, 3rd. series, Vol. 10 (1916), Sec. 4, pp. 37–38, 1917.

[4] *Geological Survey of Canada*, Sum. Report (1920), pp. 2B–3B.

[5] E. M. Spieker, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 6 (1922), pp. 118–19.

[6] *Geological Survey of Canada*, Sum. Report (1922), p. 6B.

deed, a good title for this section would be "Some Problems of Canadian Cretaceous Stratigraphy." For convenience the Paskapoo, Willow Creek, and other formations of probable post-Cretaceous age are described with the Cretaceous.

BLAIRMORE–SOUTH FORK AREAS (FIG. 1, NO. 1)

A study of a few sections (Fig. 2) along the foothills from south to north reveals some interesting variations. The stratigraphy of the Blairmore and South Fork areas has been studied in detail. The formations, in descending order, are the Allison, Colorado shale, Crowsnest volcanics, Blairmore, and Kootenay.[1] The Kootenay consists of sandstone, gray and black shale, and coal beds. The Blairmore has a persistent conglomerate bed at its base. The contact is that of a disconformity, there being evidence of some erosion of the Kootenay prior to deposition of the Blairmore; the erosion is probably not of very great magnitude, however. Above the basal conglomerate are sandstones, gray, greenish and reddish shales, and, a little above the middle, a discontinuous layer of conglomerate, very thick in places. This conglomerate contains crystalline igneous pebbles,[2] whereas the basal conglomerate has none. The Crowsnest contains bedded tuffs and agglomerates. The Colorado is a shale formation with some arenaceous zones. The Allison consists of massive sandstone in the basal part. Above this is a thin zone with very small coal seams, and higher still are bedded sandstones and shales.

Careful collections of fossil plants and invertebrates have been made in these areas and the succession of faunas and floras has been worked out. The succession of floras in the Kootenay and Blairmore formations is interesting, for it records the introduction of angiosperms (dicotyledons) into this part of the North American interior.[3] The Kootenay was found to have an old flora of ferns, cycads, and conifers, without angiosperms. The lower part of the Blairmore was found to have a similar flora, and also very rare dicotyledonous angiosperms. The upper part of the Blairmore was found to carry a flora in which the angiosperms play an important part. At first it was thought that the upper flora might be a Dakota flora and the lower Blairmore, a Comanchean (using it in the sense of Lower Cretaceous) flora.[4] Later these floras were studied by Berry, who correlated the upper flora approximately with the Cheyenne (Cenomanian) flora of southern Kansas, that is, with a pre-Dakota (pre-Turonian) flora. The lower flora he dated as Aptian or Albian and the Kootenay flora, as Barremian. Thus the boundary between Lower and Upper Cretaceous comes within the Blairmore formation. A freshwater fauna was found in the lower part of the Blairmore, coeval with the lower or Aptian–Albian flora and having two species in common with a fauna described by Stanton from the Kootenai of Montana.[5] The Kootenai of Montana appears to be equal to

[1] W. W. Leach, *Geological Survey of Canada*, Sum. Report (1911), pp. 192–200; B. Rose, *Geological Survey of Canada*, Sum. Report (1916), pp. 107–14.

[2] B. Rose, *Geological Survey of Canada*, Sum. Report (1916), p. 110.

[3] *Geological Survey of Canada*, Sum. Report (1915), p. 110.

[4] *Geological Survey of Canada*, Sum. Report (1915), p. 112.

[5] T. W. Stanton, *Proc. Amer. Phil. Soc.*, Vol. 42 (1903), pp. 188–99, Plate 4.

the Kootenay of southwestern Alberta plus at least a part of the Blairmore formation. Two Coloradoan faunas are present in the Colorado shale of these areas.

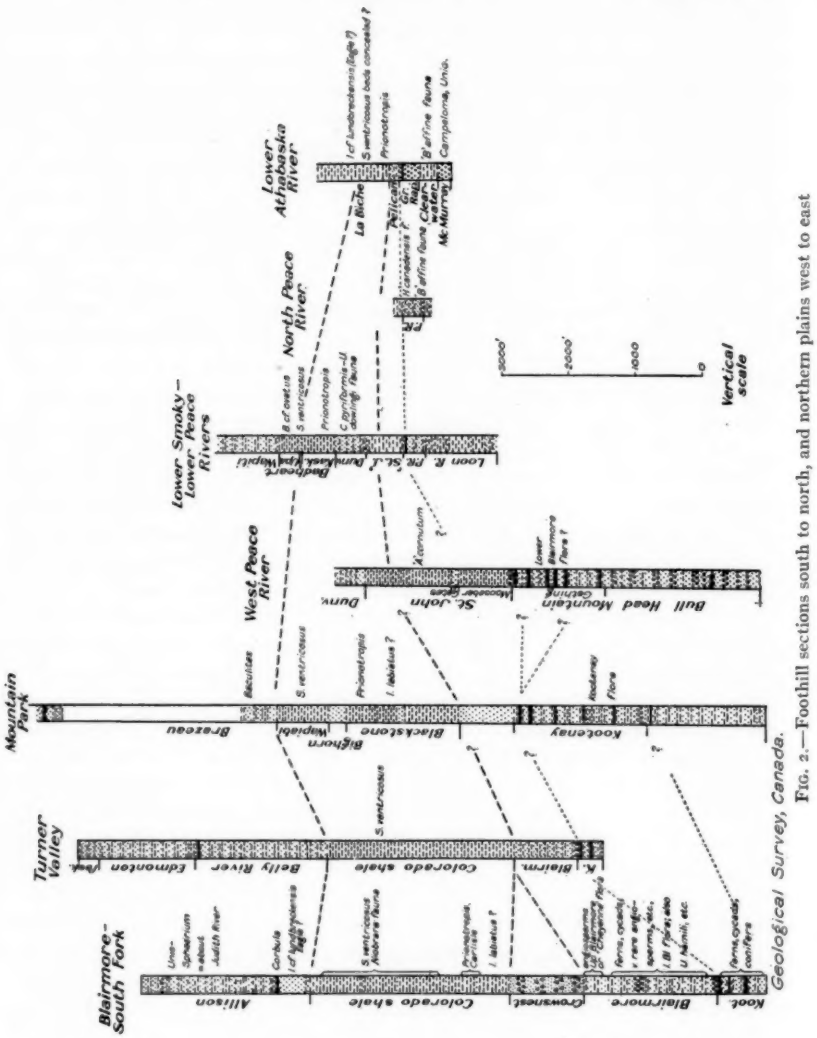

FIG. 2.—Foothill sections south to north, and northern plains west to east

The *Prionotropis*, or "Carlisle," or Middle Coloradoan, fauna occurs in shaly sandstone on South Fork, or Castle River, at a horizon considered to be somewhere in the lower half of the formation. The *Scaphites ventricosus*, or "Niobrara," or up-

per Coloradoan, fauna has a long range in the upper half or more of the formation on Crowsnest River. The basal sandstone of the Allison formation carries a sparse marine fauna, the *Inoceramus* cf. *lundbreckensis* fauna, possibly a Canadian equivalent of the Eagle fauna. In the coal zone above the massive sandstone was found a brackish fauna, including *Corbula* and a small flora, including *Zamites albertensis* Berry MS. Higher, in the sandstones and shales, occurs a freshwater fauna in two facies, a stream or lake facies in sandstone with *Unio danae*, and a pond or quiet-stream facies in shale with *Physa*, *Sphaerium*, and other forms. This fauna is probably of Judith River, or Foremost-Pale Beds, age.

TURNER VALLEY (FIG. 1, NO. 2)

Farther north, in the Turner Valley, there is little change in the section. It goes higher, the formations above the Colorado shale being the Belly River, Edmonton, and Paskapoo. Little is known of the floras of this district. The *Scaphites ventricosus* fauna has been found in the Colorado shale by Hume, but the *Prionotropis* fauna has not yet been located definitely, although Sinclair[1] has listed species of this fauna. What the relation of the Edmonton and Paskapoo of this western area is to the similarly named and more typical formations of the east is not known.

MOUNTAIN PARK (FIG. 1, NO. 3)

To the north, in Mountain Park, a very different section is found. This applies in particular to the lower part of the section. The coal-bearing strata do not here, as in the south, follow immediately above the Jurassic Fernie formation, but are separated from it by 1,800 feet of barren shale and sandstone.[2] The earlier Cretaceous here includes three members, as interpreted by MacKay;[3] in descending order there are 300–500 feet of sandstone with some shale and some conglomerate, 2,000 feet of coal, shale, and sandstone with conglomerate at the base, and 1,800 feet of shale and sandstone with a thin seam of coal in a few localities immediately under the conglomerate. A flora has been collected in the coal-bearing beds. It resembles the Kootenay closely, but as there appears to be some difficulty in distinguishing this flora from that of the lower Blairmore, the possibility of its being lower Blairmore cannot be dismissed. This is a problem for the paleobotanist. Postulating one or the other age of the middle coal-bearing part, several possible correlations of the three members with the formations of the Blairmore section will suggest themselves. Until more fossils are found, however, or until the problem of distinguishing the lower Blairmore and Kootenay floras is settled, or a sufficient number of intervening sections are studied to make lithological comparisons, suggestions are of little value. The Coloradoan strata here, as in the south, are entirely marine, but are included in three formations: the Wapiabi shale, the Bighorn sandstone, and the Blackstone shale. The *Prionotropis*, or "Carlisle," fauna

[1] *Geol. Soc. of Amer.*, Bull. 27 (1916), p. 681.

[2] B. R. MacKay, personal communication.

[3] Personal communication. See also R. L. Rutherford, "Geology of the Foothills Belt between McLeod and Athabaska Rivers, Alberta," *Scientific and Industrial Research Council* (Report No. 11, Alberta, 1925).

occurs in the black shales of the Blackstone, and the *Scaphites ventricosus*, or "Niobrara," fauna is in the Wapiabi formation. The Brazeau is marine at the base with *Baculites*; the upper part has a freshwater fauna.

Rutherford[1] has described that part of the area lying northeast of the Nikanassin range. He has placed all the strata above the Wapiabi shale in the Saunders formation, which is estimated to be 11,000 to 13,000 feet thick and consists of conglomerates, sandstones, shales, and coal beds. Fossil remains are rare, but include some fossil plants, *Unio*, and bone fragments. Rutherford interprets it as a largely non-marine equivalent of all the Montana group and of possibly even longer upward range. It underlies all the northeast area of his map, showing how deeply buried the earlier Mesozoic strata must be there.

WEST PEACE RIVER (FIG. 1, NO. 4)

Passing far to the north, a good section is exposed on West Peace River at the canyon and below it. The section here begins with a thick series of conglomerates, grits, sandstones, a few shale beds, and rare thin coal seams, the lower member of the Bull Head Mountain formation. It is followed above by the sandstones, shales, and coal beds of the Gething member of the Bull Head Mountain. At the top is a thin bed of sandstone with a few pebbles, which, to the south on Pine River, passes into a thick bed of conglomerate. The Gething contains a flora at first assigned tentatively to the lower Blairmore by the writer.[2] Later, on the advice of Berry, it was assigned to the Kootenay.[3] Later, however, after studying the lower Blairmore flora, Berry thinks the age may be lower Blairmore, or in part of this age. There is no reason why the coal of the north should not be later than that of the south. As compared with Blairmore, it may be noted that the coal-bearing strata are preceded by a thick series of conglomerates and grits which are not present in the south; they are similarly followed by a conglomerate bed, however, but it is not so uniform. Compared with the Mountain Park section the sediments underlying it are much coarser. No correlation can at present be offered of the Moose Bar shale and Gates sandstone members of the St. John formation. The upper shale member of the St. John, however, contains the sparse marine "*Acanthoceras*" *cornutum* fauna, which contains nothing in common with the other North American faunas and is probably of early Upper Cretaceous age. The St. John is followed by the Dunvegan, with its early Coloradoan fauna.[4]

[1] R. L. Rutherford, "Geology of the Foothills Belt between McLeod and Athabaska Rivers, Alberta," *Scientific and Industrial Research Council*, Report 11 (Alberta 1925).

[2] *Geological Survey of Canada*, Sum. Report (1917), p. 170.

[3] *Geological Survey of Canada*, Sum. Report (1922), p. 6B.

[4] For descriptions of areas to north and south of the canyon, see J. A. Dresser, "Oil Survey in the Peace River District, B.C.," pp. K5 to K10; and E. M. Spieker, "The Geology and Oil Resources of the Foothills South of Peace River in Northeast British Columbia," pp. K11 to K27; *Province of British Columbia*, Department of Lands, 1921. Also see E. M. Spieker, *Amer. Assoc. Petrol. Geol.*, Vol. 6, No. 2 (1922), pp. 112–38.

LOWER SMOKY AND PEACE RIVERS (FIG. 1, NO. 5)

Across the plains and on the east side of the great geosyncline the section is very different in the lower part. Here the Lower Cretaceous is chiefly marine. At the base is the Loon River shale, followed above by the Peace River sandstone, which consists of three members: a lower sandstone, a middle thin shale, and an upper sandstone. The upper sandstone member in the vicinity of the town of Peace River is a massive sandstone with a coal bed near the top and is presumably of subaerial origin. Northward and downstream the upper member is replaced laterally by shale, in part, and finally becomes a thin-bedded sandstone and shale and becomes marine, for it contains a marine fauna, the *"Hoplites" canadensis* fauna. The base of the lower sandstone member and the top of the Loon River shale, which appear above river level near Tar Island and downstream, also carry a marine fauna, named here tentatively the *"Beudanticeras" affine* fauna. These two faunas are unlike and have nothing in common with the faunas of southern Alberta. They must be northern invasions and are probably of Lower Cretaceous (post-Neocomian) age. They are certainly pre-Turonian.

Over the Peace River sandstone is the so-called "St. John" shale. Although this eastern shale has the same upper limit as the typical St. John shale of the western section, it very likely has a different downward range. It is unfossiliferous. It is probably of marine origin, for on the Canadian Plains, shales of this thickness, where fossiliferous, generally contain marine fossils. There are exceptions, of course, but on the site of the present Canadian Plains in Cretaceous time, the sands seem to have been largely retained on the marginal alluvial or delta plains or in the brackish-water embayments. The lower limit of the Colorado group comes somewhere in this formation or at its top.

The Dunvegan formation follows the "St. John" and consists of sandstone, shale, and a few thin coal seams. It contains both marine and non-marine faunas and is of early Colorado age. It is evidently a marginal delta or alluvial plain built out into the Colorado sea and submerged at times. It did not extend south to the Mountain Park area, but may have extended eastward to the lower Athabaska River where the thin Pelican sandstone may be an eastern extension of it. It is the only example known of a marginal alluvial plain in the Coloradoan of the Canadian Plains.[1] This is to be contrasted with the widespread and persistent marginal alluvial or delta Belly River plain of the succeeding Montana epoch.

The Smoky River formation has three members: a lower shale member, the Kaskapau, a middle sandstone member, the Badheart, and an upper shale member, not named. In the lower part of the Kaskapau shale the *Prionotropis*, or "Carlisle," fauna is present at two horizons. In the top of the Kaskapau shale and in the Badheart sandstone the *Scaphites ventricosus*, or *"Niobrara,"* or upper Colorado, fauna appears. The upper shale member contains *Baculites* cf. *ovatus* and is of Montanan age. The Wapiti formation consists of sandstone, shale, and some thin coal beds, and is, in part at least, of Montanan age.

[1] Of course there may have been marginal delta plains far to the west.

LOWER ATHABASKA RIVER (FIG. 1, NO. 7)

The section on lower Athabaska River is similar to that on lower Peace River. The Cretaceous formations, in descending order, are the La Biche shale, the Pelican sandstone, the Pelican shale, the Grand Rapids sandstone, and the McMurray sandstone (Tar sands). The McMurray has sloping foreset-like beds below and horizontal topset beds above. It contains a freshwater fauna with *Campeloma*

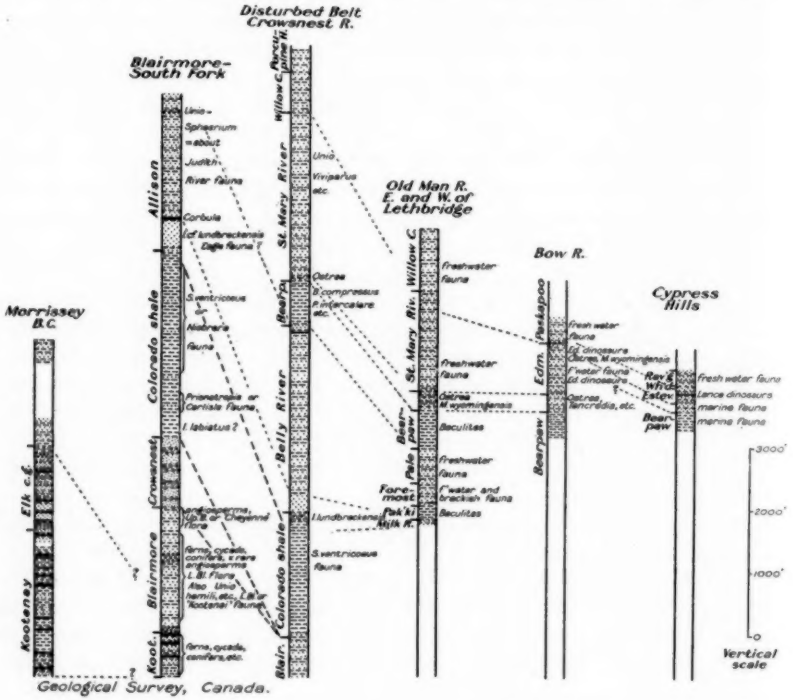

FIG. 3.—Sections in southern mountains and plains west to east

and other forms. The Clearwater formation consists of sandstone and shale, including greenish sandstones and shales, and contains a marine fauna, the "*B*" *affine* fauna, similar to that at the base of the Peace River sandstone and the top of the Loon River shale on Peace River. The Grand Rapids formation consists of sandstone and some shale and has a thin coal seam near the top. The Grand Rapids is approximately the equivalent of the Peace River sandstone on Peace River, and the Clearwater shale and McMurray sandstone are about the equivalent of the Loon River, that is, the Loon River below the Peace River sandstone.

The Pelican shale has a few fragmental *Inoceramus* specimens and is about the

equivalent of the "St. John" on the lower Peace. The Pelican sandstone is unfossiliferous, but may be an eastern extension of the Dunvegan.

The La Biche carries in its basal part a *Prionotropis* fauna. The *Scophites ventricosus* fauna was not found, but the beds containing it may be concealed. Higher is an *Inoceramus* cf. *lundbreckensis* fauna which may be an equivalent of a similar fauna in the base of the Allison formation at Blairmore, tentatively correlated with the Eagle. Higher in the LaBiche there may be a later Montanan fauna, but the writer has few data to offer.

A west-to-east series of sections is shown in Figure 3, across the southern mountains and plains from eastern British Columbia to the western border of Saskatchewan.

MORRISSEY, B.C. (FIG. 1, NO. 8)

Near Morrissey, B.C., on the west side of the Rocky Mountains, an interesting section was measured by McEvoy,[1] consisting below of shale, some sandstone, and thick coal beds; in the middle, of interbedded shale, sandstone, conglomerate, and very thin coal seams; and at the top, of sandstone and shale. The lower member is the local Kootenay formation, and the middle member, the Elk conglomerate. A Kootenay flora was collected in the vicinity, but its exact stratigraphic position is not known. Until more fossil collections are made from this locality no exact correlation can be made with Blairmore. A tentative correlation may be attempted, however, comparing the lower coal-bearing member with the Kootenay formation of Blairmore, the Elk conglomerate with the basal part of the Blairmore formation, and the uppermost sandstone and shale member with other and higher parts of the Blairmore formation.

DISTURBED BELT (FIG. 1, NO. 9)

The Disturbed belt east of the Blairmore map-area has been studied by Stewart.[2] The section is much like that in the Blairmore area. The Colorado shale contains the *Scaphites ventricosus* and probably also the *Prionotropis* fauna. At the top is the *Inoceramus lundbreckensis* fauna, of approximately the same date as that in the lower part of the Allison formation to the west. The basal part of the Belly River contains massive sandstone, as in the basal part of the Allison, and it is probable that this sandstone and part of the Colorado shale are, like the basal massive sandstone of the Allison, of about Eagle date. Above the Belly River formation is the Bearpaw marine formation, not present in the Blairmore area, with *Baculites compressus*, *Placenticeras intercalare*, and other forms. Near the base of the St. Mary River formation is a brackish fauna including *Ostrea*. Above is a freshwater invertebrate fauna in a long range, the St. Mary River fauna, with *Unio*, *Viviparus*, and *Campeloma*. Higher come the Willow Creek and Porcupine Hills beds with freshwater faunas.

[1] J. McEvoy, *Geological Survey of Canada*, Annual Report, Vol. 13, new series (1900), pp. 86A–90A.

[2] J. S. Stewart, "Geology of the Disturbed Belt of Southwestern Alberta," *Geological Survey of Canada*, Memoir 112, 1919.

LETHBRIDGE (FIG. 1, NO. 10)

There is a good section along Oldman River, east and west of Lethbridge, recently restudied by W. S. Dyer.[1] At the bottom is the Milk River sandstone, probably an Eagle equivalent, but unfossiliferous in Canada. Then follows the marine Pakowki shale, marking an early westward penetration of the Pierre sea, which, it may be noted, did not extend as far west as the Disturbed belt on Crowsnest River. Above are the Foremost sandstone, with brackish and freshwater faunas, and the Pale Beds, with a freshwater fauna, both together about the equivalent of the Judith River of the United States interior. Higher are the Bearpaw, with its marine fauna, the brackish zone, with *Ostrea* and *Melania wyomingensis*, and the St. Mary River and the Willow Creek formations, with their freshwater faunas.

BOW RIVER (FIG. 1, NO. 11)

A section on Bow River, in the vicinity of Bassano and to the north, has recently been examined by Dyer.[2] At the bottom is the marine Bearpaw, followed above by the brackish zone, more marine here, however, than at Lethbridge, with *Ostrea* and *Tancredia*. It is followed by the Edmonton, which Dyer interprets as in part equivalent to the St. Mary River. It carries a freshwater fauna and dinosaur bones near the middle, and a brackish fauna with *Ostrea* and *Melania wyomingensis* somewhat higher. The Paskapoo is at the top of the section and is separated from the Edmonton by an erosional break of unknown magnitude.

RED DEER RIVER

A similar section, farther to the north on Red Deer River, has been described, in late years, by Barnum Brown,[3] J. A. Allan,[4] and others. It is from this section that most of the Edmonton dinosaurs have come. They have a long range in the formation, but have not been found in the upper 100 feet. The dinosaurs are intermediate in age between those of the Belly River and those of the Hell Creek or Lance but probably closer to those of the Lance.[5] It was here that the disconformity between the Edmonton and Paskapoo formations was discovered by Sanderson.[6] Allan and Sanderson claim that a maximum thickness of 450 feet of Edmonton strata was removed prior to the deposition of the overlying Paskapoo formation. The time interval which this break marks will be known only when the age of the Paskapoo formation is solved.

[1] This section is based on his observations. See also D. B. Dowling, *Geological Survey of Canada*, Memoir 93, 1917.

[2] W. S. Dyer, personal communication.

[3] Barnum Brown, *Bull. Geol. Soc. of Amer.*, Vol. 25 (1914), pp. 355–80.

[4] J. A. Allan, "Geology of Drumheller Coal Field, Alberta," *Scientific and Industrial Research Council*, Report 4 (Alberta, 1922).

[5] Barnum Brown, *op. cit.*, p. 380.

[6] J. A. Allan and J. O. Sanderson, Abstract in *Bull. Geol. Soc. of Amer.*, Vol. 36 (1925), No. 1, p. 161; J. A. Allan, *Bull. Canadian Inst. Mining and Metallurgy* (April, 1925), p. 396.

CYPRESS HILLS (FIG. 1, NO. 12)

Farther to the east a somewhat different section occurs in the Cypress hills on the border of Alberta and Saskatchewan. It has been studied by Davis,[1] Sternberg,[2] Dyer,[3] and others. At the base is the marine Bearpaw shale; above is a marine sandstone, followed by the Estevan sandstone and shale with Lance dinosaurs, the Whitemud sandstone, and the Ravenscrag shale and sandstone with a freshwater invertebrate fauna. Now if the Edmonton and St. Mary River are of the same age, then the marine beds that precede them are earlier in age than those that precede the Estevan beds in the Cypress Hills, for the Edmonton dinosaurs are considered to be earlier in age than the Lance dinosaurs, and Sternberg has identified Lance dinosaurs in the Estevan. Thus marine conditions prevailed longer in the east than in the west, and the non-marine beds of the delta or alluvial plain advanced very slowly eastward, if this correlation be correct. The problem also must be met: What is the equivalent of Lance or Estevan in the Bow River and Red Deer River sections? Is it represented by uppermost Edmonton, by the erosional unconformity between the Edmonton and Paskapoo, by the earliest Paskapoo, or by combinations of these? If the age of the Paskapoo can be determined and is post-Lance, then the deposition of the Estevan may be of the same date as at least a part of the erosion of the Edmonton. It is probable that some of the sediments which are the result of thorough leaching, as in the Whitemud beds, have come from the east. It is interesting to notice also, in the columnar sections, the marked decrease in thickness of sediments eastward.

FAUNAL LISTS

For convenience of geologists in the field, lists of important and diagnostic fossils are here given.

The McMurray fauna includes unpublished species of *Campeloma*, *Pachymelania*, and *Unio*. The "*B*" *affine* fauna includes "*Beudanticeras*" *affine* (Whiteaves), "*Hoplites*" *mcconnelli* Whiteaves, *Tellina dowlingi* McLearn, *Nemodon mcconnelli* McLearn, *Pinna curvimarginata* McLearn, *Inoceramus dowlingi* McLearn, *Brachydontes athabaskensis* McLearn, and unpublished species of "*Beudanticeras*," *Cyprina*, *Cardium* (*Laevicardium*), *Protocardium*, *Pecten*, *Oxytoma*, *Nucula*, and *Yoldia*. The "*H*" *canadensis* fauna includes "*Hoplites*" *canadensis* Whiteaves, unpublished species of "*Hoplites*", *Trigonia albertensis* McLearn, and *Dicranodonta dowlingi* McLearn. The "*Acanthoceras*" *cornutum* fauna includes "*Acanthoceras*" *cornutum* Whiteaves, *Nucula dowlingi* McLearn, and a large flat, unpublished species of *Inoceramus*. The lower Blairmore freshwater fauna includes *Unio douglassi* Stanton and unpublished species of *Unio* and *Corbula*. Important fossils in the Dunvegan are *Unio dowlingi* McLearn, *Tellina dunveganensis* McLearn, *Brachydontes multilinigera* Meek, *Barbatia micronema* (Meek), *Corbula pyriformis* Meek, *Inoceramus dunveganensis*

[1] N. B. Davis, "Clay Resources of Southern Saskatchewan," *Mines Branch, Dept. of Mines*, Canada (1918), pp. 5–14.

[2] C. M. Sternberg, *The Canadian Field-Naturalist*, Vol. 38 (1924), No. 4, pp. 66–70.

[3] Personal communication.

McLearn, *Rhytophorus? caurinus* McLearn, and *Pachymelania?* sp. Important guide fossils in the *Prionotropis*, or "Carlisle", fauna in Canada are the genus *Prionotropis*, *Inoceramus corpulentus* McLearn, and small inornate *Baculites*. The *Scaphites ventricosus* or "*Niobrara*" fauna is readily recognized in Canada by *Scaphites ventricosus* M. and H., a new species and variety of *Scaphites* closely related to *S. ventricosus*, *S. vermiformis* M. and H., *Placenticeras syrtale* (Morton), *Inoceramus exogyroides* M. and H., *I. pontoni* McLearn, *I. coulthardi* McLearn, and medium-sized *Baculites* with *anceps* and *asper*-like ornament. The *Inoceramus lundbreckensis* fauna on Crowsnest River, east of the Blairmore sheet in the Disturbed belt includes *Inoceramus lundbreckensis* n. sp., and *Baculites* cf. *asper* Morton. Farther west, in the base of the Allison formation, the *Inoceramus* cf. *lundbreckensis* fauna includes this species 100 feet above the visible base of the formation, and 85 feet higher are unpublished species of *Legumen* and *Ostrea*, *Pteria* sp., and shark teeth. The *Inoceramus* cf. *lundbreckensis* fauna on Athabaska River in the LaBiche shale includes *I.* cf. *lundbreckensis* and *Baculites* cf. *ovatus*. The higher Montanan, or Pierre, faunas in the Pakowki, Bearpaw, and other formations are recognized by large species of *Baculites*, *Placenticeras intercalare* Meek, *Scaphites nodosus* Owen, *Inoceramus tenuilineatus* Hall and Meek, *Cyprina ovata* var. *alta* Whiteaves, and *Lucina occidentalis* Morton.

The higher formations, the St. Mary River, Edmonton, and others, contain freshwater invertebrate faunas which are being studied by Dyer. By noticing small advances in the evolution of species, it is possible with some facility to distinguish the Belly River non-marine from the later formations, that is, St. Mary River and Edmonton, and it is hoped that it may also be possible to distinguish St. Mary River from the later Fort Union and other beds.

STRUCTURE AND OIL PROSPECTS

G. S. HUME

THE FOOTHILLS BELT

The western part of the foothills belt lying in proximity to the mountains is extremely faulted and folded and, in general, the structure consists of a series of westward-dipping overthrust fault blocks (Fig. 4). This has given rise to parallel ridges mostly capped by the more resistant members of the rocks, whereas the valleys represent areas of less resistant strata that have been more easily eroded or represent erosion along fault lines. Fault planes are rarely seen except where transverse streams have cut across the strike of the ridges. The evidence of faulting between the ridges depends for the most part on the relationship of strata on adjoining ridges and the interpretation of topography.

In a general way it is true that metamorphism of the rocks decreases from west to east in the foothills; and in the eastern part, at least, there are structures which are considered favorable for oil and gas accumulations. Drilling tests are now in progress on several of these structures from Bow River south to the international boundary, the principal areas being Jumpingpound, Moose Mountain, Turner Valley, Highwood, and Rice Creek, with the principal effort being directed toward the development of Turner Valley, where more than twenty-five wells are in vari-

ous stages of drilling progress. Only one of these areas, Turner Valley, has been examined by the Geological Survey in detail.

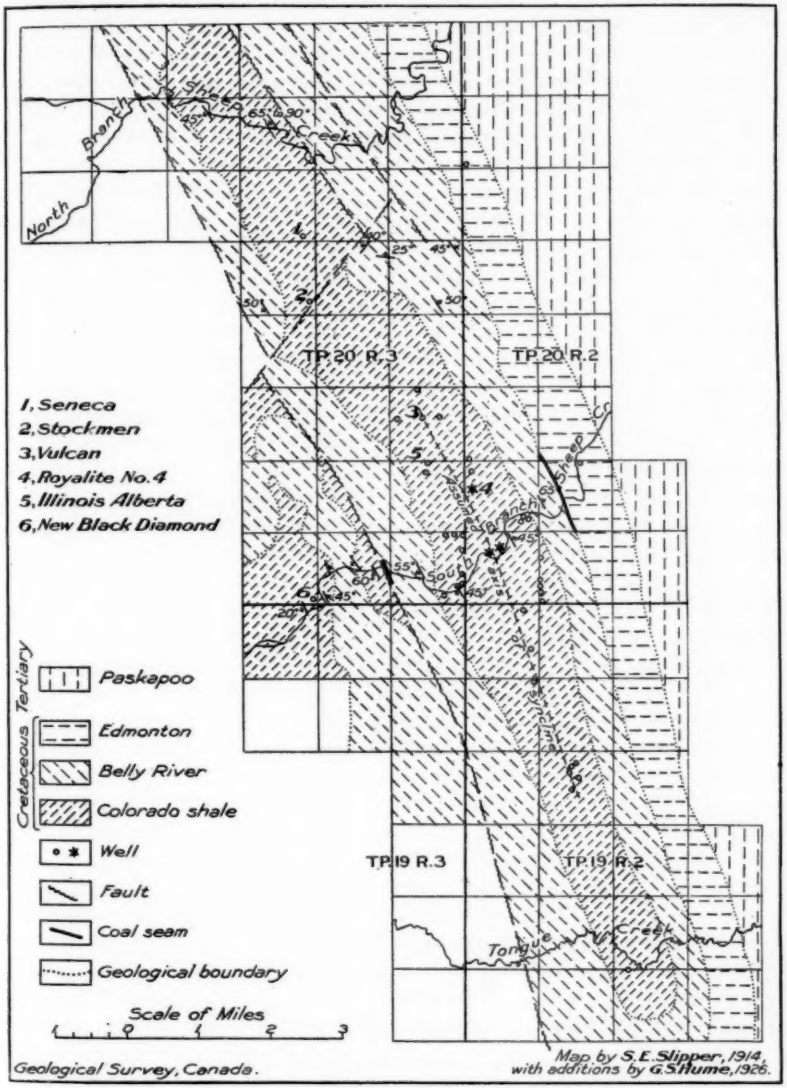

FIG. 4.—Geological maps of Turner Valley field

TURNER VALLEY

A geological map[1] by S. E. Slipper, published as the result of work done in 1914 for the Geological Survey, gives the outline of the geology of the field. Work done by the Geological Survey subsequent to the publication of Slipper's map has entirely confirmed the division of geological formations as already outlined, and such additions as have been made to the map are only in detail of position of boundaries and in detail of structure as additional information has become available from wells drilled within the field. The following description is, therefore, based on Slipper's report, with some additional information regarding structure.

Turner Valley is an anticlinal structure with the south branch of Sheep River cutting across it from west to east in the central part, thus giving a fairly good geological section across the strike. North of Sheep River, parallel ridges of Belly River rocks (Montana) on either side of a central valley clearly show the anticlinal relationship, the rocks on the eastern flank dipping eastward at angles as great as 60 degrees and the rocks on the western ridge dipping westward at angles possibly even greater. In the valley between these parallel ridges the Belly River rocks are eroded and the underlying Colorado shales are exposed. This anticlinal structure is easily traceable about 4 miles in an approximate northwest direction from Sheep River, beyond which it is cut off by what is supposed to be a normal fault with downthrow on the northern side. The amount of throw of this fault has not been determined, but on the western side of the valley the fault is suggested by a break in the continuity of the Belly River ridge which forms the western flank of the anticline, and also suggested by a slight offsetting to the east of the ridge north of the fault. A fault is shown here on Slipper's map, but was not produced across the valley in a northeast direction. That the fault probably does extend across the valley is shown by a sharp change in the strike of the Belly River rocks on the eastern flank of the anticline, although, due to the absence of exposures in the valley, there are no data on the fault between the two ridges, that is, in the part underlain by Colorado shales. However, since evidence of faulting is known from both the western and eastern ridges in hard Belly River rocks, the supposition is that the softer Colorado shales have at least yielded along a line of dislocation which probably is a fault. One well, the Stockmen's (Fig. 4, No. 2), is now drilling close to the supposed fault line[2]. Judging from position, this well began north of the fault line, but it is suspected that at depth it should pass through the line of dislocation or faulting and reach the prospective oil and gas horizons on the upthrow side. The upthrow side of the fault seems to offer an exceptionally favorable position on the anticlinal structure for accumulation of gas and oil, and this well, therefore, is of particular interest in testing the Turner Valley field at the extreme northern end, where the structure is anticlinal. This, however, does not mean that Turner Valley north of the transverse fault has no oil and gas possibili-

[1] "Sheep River Gas and Oil Field, Alberta," *Geological Survey of Canada*, Memoir 122, 1921.

[2] The Stockmen well has now penetrated the transverse fault but apparently has passed into the northern extension of the Vulcan syncline on the upthrow side of the fault.

ties, but that the conditions north of the fault are somewhat different from those encountered south of the fault. North of the transverse fault the valley continues some distance without break, being bounded on the east and west by the parallel ridges of Belly River rocks. For this part of the valley, Slipper has shown a fault on the east side between the Colorado shales and the Belly River formation and in a general way a westerly dip from east to west from the vicinity of the fault. The west dip of the strata is shown by exposures on the north branch of Sheep River about the center of Sec. 3, T. 21, R. 3, where the dip is approximately 65°, although in exposures farther west, the dip is considerably less. Thus the structure for this part of Turner Valley appears to be a westward-dipping fault block rather than an anticline. Several wells have been located on this fault block; one, the Seneca, is at present drilling. Since the transverse fault already described is believed to be downthrown to the north, it follows that for comparable drilling sites north and south of the fault, the northern locations are likely to require deeper drilling, the difference in depth, however, depending only partly on the amount of throw on the transverse fault. Equally good reasons may be suggested for anticipating a favorable accumulation of oil and gas against the thrust fault on the eastern side of the fault block as those advanced for a similar accumulation against the upthrow side of the transverse normal fault. The Seneca well (Fig. 4, No. 1) is located approximately in the center of the valley and it is believed to be favorably situated to test the possibilities of this fault block. Since other fault blocks in different parts of the foothills are of the same type as this one which is being tested, this well is of special importance.

In the central part of Turner Valley in the area north of Sheep River the data available from wells drilled are sufficient to show that instead of a single anticline occupying Turner Valley, there are two anticlines, with a sharp syncline in the center of the field. This syncline is distinctly shown by outcrops on Sheep River and is shown on Slipper's map as a relatively small feature. Its magnitude was not suspected until the Vulcan well (Fig. 4, No. 3), drilling in the center of the valley about 2 miles north of Sheep River, found it to be very deep, at least for this part of the field, the depth being in excess of 1,400 feet below the crest of the eastern anticline, at the lowest productive horizon of the field. The Geological Survey has no definite information on the age of the lowest productive horizon, but a core from 3,811 feet in the Illinois-Alberta well shows some crinoid stems and corallites that are regarded by E. M. Kindle as representing a late Paleozoic age, although some geologists have regarded the age as Triassic.

A noteworthy feature of the eastern anticline on which No. 4 Royalite well (Fig. 4, No. 4) is located is the fact that the anticlinal axis, instead of being vertical, has a westward dip, but the data available are not sufficient to determine the amount of dip. The attitude of the axis of the western anticline has not been determined, although the wells that have been drilled show there are possibilities of production equal to that already found on the eastern anticline.

South of Sheep River, several wells are being drilled, and it is thought that

conditions exist similar to those north of Sheep River, that is, an eastern and a western anticline separated by a sharp syncline, all within the continuation of Turner Valley southward. No well south of Sheep River has reached the lower productive horizon supposed to be Paleozoic, but higher horizons have been penetrated at a sufficiently shallow depth to show that the structure is as favorable for this part of the field as north of Sheep River. There is also the possibility of oil production from the Blairmore formation. The top of the Blairmore formation is a persistent oil horizon wherever penetrated in the field, but present information does not justify the expectation of large productivity.

Another structure should be mentioned in connection with this area, although structurally it is entirely distinct from Turner Valley. This structure is known as the New Black Diamond anticline, on account of a test now being made on it by the New Black Diamond Oil Company (Fig. 4, No. 6). It is about 2 miles west of Turner Valley along Sheep River. Structurally it is separated from Turner Valley by a thrust fault that brings Benton shales in contact with the top of the Belly River formation or possibly the base of the Edmonton, which overlies the Belly River. The throw on this fault is thus in excess of the thickness of the Belly River formation, which comprises approximately 2,000 feet of strata. From the sections exposed on Sheep River west of the thrust fault it is known that the dip not far west of the fault is rather steep, but within a relatively short distance these dips become much more gentle, and somewhat farther west are reversed, giving a small syncline which brings Belly River rocks to the level of the river. Westward from this syncline the dips increase, and about 3,000 feet west of the base of the syncline there is a small area which is a zone of considerable disturbance; but it is probable that a fault, if such be present, is rather small and may have little or no significance at depth. West of the zone of disturbance the dips are about 40° E. but decrease rapidly to the crest of an anticline where the New Black Diamond well is located. Southwest of the crest of the anticline, for about a mile, there are westward dips of 20° to 30°, beyond which is an area of marked disturbance with close folding and some faulting. The fold just described is clearly indicated on the Geological Survey map by S. E. Slipper, and in view of the fact that there are lower dips on this fold than occur over a considerable part of the Turner Valley structure, it is very probable that the deep dolomitic horizon of Turner Valley will be reached at considerably less depth. The New Black Diamond structure strikes northwest and southeast, parallel to Turner Valley, but its extent is not definitely known. It is generally considered that the amount of metamorphism increases from east to west in the foothills, and therefore it would be anticipated that metamorphism might be greater on the New Black Diamond structure than in the Turner Valley structure. This, however, may be partly offset by the fact that the New Black Diamond structure is not so sharp a fold as Turner Valley; and although the shales in the two anticlines are superficially alike in appearance, shales of the same age in the more disturbed area to the west of the New Black Diamond structure are more indurated and slaty in appearance, indicating much greater metamorphism. It is well recognized that the carbon ratios of coals are the best index of metamorphism.

A coal seam at the top of the Belly River formation exposed at Lineham on the eastern flank of the New Black Diamond anticline shows that the coal has a carbon ratio of 58.1, whereas on the eastern flank of Turner Valley, from a coal seam at approximately the same horizon, a carbon ratio of 57.3 is indicated. The coal exposed in the Lineham seam is close to a fault which it is considered might affect the carbon ratio; but so far as carbon ratios are an index to metamorphism, it would appear from data available that the carbon ratio for coal from the Lineham seam is within the limits where oil and gas might be predicted. This carbon ratio is applicable only to Cretaceous rocks, and a higher degree of metamorphism is undoubtedly present in older rocks; but since oil and gas have been found in an area where the nearest coal seam indicates a favorable degree of metamorphism, it follows that the New Black Diamond structure should also be considered favorable. Thus from the standpoint of both structure and metamorphism the New Black Diamond structure is worthy of commendation, and the well now being drilled by the New Black Diamond Oil Company is of particular interest in testing an entirely new structure.

THE PLAINS AREA

Eastward from the foothills the rocks dip eastward into what is generally known in southern central Alberta as the Alberta syncline. A belt of variable width but nowhere greater than 100 miles east and west is overlain by Tertiary rocks of non-marine origin. In this area the lower dolomitic zone productive in Turner Valley is at a depth that may be found prohibitive for drilling, although it is possible that some of the higher horizons within at least part of the area may be tested. In this connection also it is to be noticed that in a northeast direction from the foothills the Jurassic, Triassic, and Carboniferous formations are believed to wedge out, since in the northern part of eastern Alberta, in the Athabaska River area, Cretaceous strata rest on those of Devonian age. In southeastern Alberta strata of Jurassic and Carboniferous ages are known to have been penetrated in the Drazen well in Sec. 34, T. 13, R. 2, W. 4th mer., but it is not known that Triassic is present. Thus it might be inferred that at least Jurassic and Carboniferous rocks are likely to be present at depth in the Alberta syncline in the southern part, but their presence in the north is much more problematical.

In southern Alberta east of the Alberta syncline is found the northward extension of the Sweet Grass arch. This structure is indicated on structural maps compiled by D. B. Dowling and issued by the Geological Survey.[1] From the international boundary on the Sweet Grass arch the strata dip radially into Alberta, and at several places, supposedly on local subsidiary folds, gas fields have been developed. In the vicinity of the international boundary some oil has been reported, but no well yet drilled in Canada in this area has given a commercial supply. It is believed, however, that this area still has structures not yet tested that offer oil possibilities.

In regard to the eastern central part of Alberta, there is an area east of Alberta

[1] D. B. Dowling, S. E. Slipper, and F. H. McLearn, "Investigation in the Gas and Oil Fields of Alberta, Saskatchewan, and Manitoba," *Geological Survey of Canada*, Memoir 116, 1919.

syncline that gives promise of producing oil fields. Owing to a mistaken identity of formations it was formerly thought that this part of Alberta was a broad anticline, known as the Battle River anticline.[1] The structure was based on the supposed presence of Bearpaw shales both east and west of a central belt of Belly River rocks. It is now known that Bearpaw occurs only on the west, and that shales exposed east of the Belly River belt are older than the Belly River; so that instead of the structure being anticlinal in this part of Alberta, it is in reality monoclinal, a feature that was first pointed out by Allan[2] and Slipper.[3] Over this monoclinal structure in Alberta the dip of the rocks is southwesterly, but east of the Alberta-Saskatchewan boundary the dip changes to southeasterly, giving the crest of the major structure in the vicinity of Battle River at the Alberta-Saskatchewan boundary. Considering eastern Alberta and western Saskatchewan, therefore, the structure is anticlinal; but this structure is not the Battle River anticline that was formerly thought to be present. On this structure a number of subsidiary folds have been discovered. These are, from west to east, Viking,[4] Hawkins, Fabyan, Wainwright-Battle River, and Ribstone-Blackfoot.[5] The last-named is on the crest of the major structure at the Alberta-Saskatchewan boundary. Results of drilling on these folds have shown gas in the Viking and Hawkins folds, gas with some oil in the Fabyan fold, and oil and gas in the Wainwright–Battle River fold. The Ribstone-Blackfoot fold is now being tested by several wells. If this relationship of gas in the western structures and oil to the east holds true for structures still farther east, it follows that the Ribstone-Blackfoot area should be the most favorable oil prospect yet located in this part of Alberta. The crest of the Ribstone-Blackfoot anticline is 275 feet above the base of a small syncline to the west on the base of the Belly River beds. This amount of closure is exceeded on the east and south, but in a northeast direction there are no available data, as no outcrops occur and no wells have been drilled. It is possible, therefore, that there may be little or no closure to the northeast, and if this be so the structure would be more accurately described as an anticlinal nose rather than an anticline. How far such a condition might affect possible accumulations of oil and gas cannot be determined, nor can the character of the sands in the structure be predicted until wells are drilled. In the Wainwright–Battle River fold two horizons are believed

[1] J. B. Tyrrell, "On a part of Northern Alberta and Portions of Adjacent District of Assiniboia and Saskatchewan," *Geological Survey of Canada*, Ann. Rept., new series, Vol. 2 (1886), Part E.

[2] J. A. Allan, "Sections along North Saskatchewan River and Red Deer and South Saskatchewan River between the Third and Fifth Meridian," *Geoolgical Survey of Canada*, Sum. Rept. (1917), Part C, pp. 9–13.

[3] S. E. Slipper, "Viking Gas Field, Structure of Area," *Geological Survey of Canada*, Sum. Rept. (1917), Part C, pp. 6–9.

[4] G. S. Hume, "Oil and Gas Prospects of the Wainwright-Vermilion Area, Alberta," *Geological Survey of Canada*, Sum. Rept. (1924), Part B, pp. 1–22.

[5] G. S. Hume, "Oil Prospects in the Vicinity of Battle River at the Alberta-Saskatchewan Boundary," *Geological Survey of Canada*, Sum. Rept. (1925), Part B.

to have produced oil. The upper of these is thought to be at the base of the Benton (Colorado) and the other is thought to be Lower Cretaceous sediments. The lower of these offers the best prospects for production in the Wainwright–Battle River field as the quality of oil (18°–19° Bé.) from it is superior to that (about 12° Bé.) from the other. In the Ribstone–Blackfoot area the first well to be drilled is that of Imperial (Ribstone) No. 1. This well encountered a considerable volume of gas at approximately 1,400 feet in depth and has found an oil sand, supposedly in the Lower Cretaceous, at a depth between 1,870 and 1,900 feet. Preparations are now under way to test this oil sand.

The Ribstone-Blackfoot fold is thought to extend northeast into Saskatchewan, but east of this area in Saskatchewan and Manitoba no folds have yet been located, for the surface, except along river valleys, is extensively covered with drift.

RELATION OF STRUCTURE TO OIL PRODUCTION IN TURNER VALLEY

Turner Valley has come into prominence chiefly as the result of production from Royalite No. 4 (Fig. 4, No. 4) well. This well is on the eastern of the two anticlines occupying at least part of Turner Valley, and has produced approximately 500 barrels of naphtha of 73° Bé. a day for more than two years. The well is producing about 17,000,000 cubic feet of gas a day, and the naphtha is extracted by passing the flow through two Smith separators. A varying amount of gas, according to the demand, is sold to the gas company supplying the city of Calgary, and a considerable amount is being burned for fuel for drilling purposes in Turner Valley. The horizon from which the naphtha and gas are being derived was reached in Royalite No. 4 well at a depth of 3,740 feet in dolomite that is probably late Paleozoic. Since Royalite No. 4 well was brought in, several other wells have been drilled to the Paleozoic and sufficient data are available to determine definitely that the productive horizon extends over considerable area with the limits as yet undefined. No well drilled has reached the lower productive horizon at a depth as shallow as Royalite No. 4 well; and from data now available there appears to be a relation between position on the structure and the quality of oil likely to be produced. The Illinois-Alberta well (Fig. 4, No. 5), being drilled on the western anticline and reaching the lower productive dolomite at a somewhat greater depth than Royalite No. 4 well, has shown considerable oil of a gravity somewhat heavier than the naphtha from Royalite No. 4 well; whereas the Vulcan Oil Company, drilling in the syncline separating the two anticlines of the Turner Valley structure, has already encountered a considerable volume of gas and some oil of about 50° Bé. in the dolomite, although at the time of writing the well is supposedly not deep enough to have reached the main productive horizon. The Vulcan well in the syncline is more than 1,400 feet lower than Royalite No. 4 well on the anticline at the top of the dolomitic horizon, and it is very significant that even at this depth oil and gas have been encountered and water is absent. A consideration of the above data points to the conclusion that the flow of wet gas and

naphtha such as are present in Royalite No. 4 well may be derived from a large reservoir containing oil of a light grade which would be classed, however, as a light crude oil. Thus, from the information from wells drilled it would be expected that from the dolomite the light naphtha and wet gas will be found in wells that are high on the structure, whereas the gravity of the oil found will increase progressively down the flanks for an unknown distance, but probably more than 1,400 feet measured vertically, as shown by the Vulcan well in the syncline between the two anticlines. The data on which a vertical gradation in the gravity of oil is based are very limited on account of the few wells drilled to the lower productive horizon, but at least they are very suggestive of such a condition.

RELATION OF FOLDING TO FAULTING AND ACCUMULATION OF OIL

As has already been shown, the foothills structure is in the main a series of overthrust fault blocks from the west. It is inevitable, therefore, that some amount of folding occurred prior to the stage in deformation when the strata yielded by faulting. Unfortunately no data have yet been discovered to show the length of the interval between folding and faulting. Whether oil accumulation preceded or followed faulting is conjectural for the most part. The cross fault described as a normal fault with northeast trend in the northern part of Turner Valley clearly shows, however, that it occurred subsequent to the folding of Turner Valley anticline. Proof of this is found in the offsetting of the Belly River ridge on the west side of the valley and the changes in strike of the Belly River rocks on the eastern side of the valley. The relationship of this fault to the northwest-trending thrust faults suggests that the normal fault also cuts the thrust faults and thus gives no data on the relation of the thrust faults to the folding, but it is assumed that the thrust faulting resulted, due to an accumulation of stress immediately following, or practically contemporaneous with, the last stages of folding.

The proof, however, that the cross fault at the northern end of Turner Valley is subsequent to folding is important from the standpoint of development of the fault block on which the Seneca well (Fig. 4, No. 1) is now being drilled. It is now practically certain that the central syncline in which the Vulcan well is located is present for a long distance through the central part of Turner Valley. As the folding preceded the cross faulting it might be anticipated that this central syncline should extend into the fault block to the north of the anticlinal structure and hence would also be downfaulted to the north by the normal fault crossing Turner Valley. The position of the syncline, if such is present, in the northern end of the valley has not been ascertained; but, as pointed out by O. B. Hopkins in a discussion of this problem with the writer, unless some structure such as a syncline or fault within the fault block is present, much too thick a section of Colorado shales is indicated by the dips of such outcrops as are exposed along the North Branch of Sheep River.

It might be assumed that accumulation of oil began at the beginning of the period of folding and was continuous until the period of folding and faulting had

been completed. If this is so, the fault block north of Turner Valley anticlinal structure would seem to have equally as good an opportunity for accumulation of oil as the anticlinal structure, provided the fault on the eastern edge of the fault block was sealed sufficiently to prevent excessive loss by migration upward through the broken fault zone. It would be expected, however, that some readjustment of the oil to the most favorable position would follow as the result of the normal faulting cutting off the anticlinal structure to the south from the fault block to the north.

As the majority of structures in the foothills will probably prove to be faulted, these considerations, although speculative, would seem to give good reason to hope that fault blocks in which conditions of structure and stratigraphy are favorable for oil and in which metamorphism has not been too severe, offer oil prospects.

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THE PETROLIFEROUS BELT OF CENTRAL-WESTERN MENDOZA PROVINCE, ARGENTINA[1]

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ABSTRACT

There are five oil-producing districts in Argentina, namely, Comodoro Rivadavia, Neuquen, Cerro Alquitran, Cacheuta, and the Jujuy-Salta district. All but the first-mentioned of these are situated in the eastern foothills belt of the Andes Cordillera.

In western Mendoza, strata of Jurassic, Cretaceous, and Tertiary age are widely exposed. They have been folded, faulted, and tilted, folding being most conspicuous in the older series outcropping to the west, and faulting and tilting being most conspicuous in the younger series more widely represented to the east.

Volcanic activity during early Tertiary time resulted in the intrusion of the older sediments by andesitic plugs, the outpouring of lavas of similar composition, and the deposition of thick beds of agglomerate.

Within the Jurassic is a thick petroliferous shale from which available evidence indicates that oil was formed by pressure and heat attendant on the intrusion of the andesitic plugs and perhaps by pressure and heat due to faulting.

Geologic structures which may possibly be oil-bearing include anticlines, domes above concealed intrusive masses, some types of faults, and porous beds uptilted against igneous plugs.

GENERAL DESCRIPTION

Location.—The Province of Mendoza in Argentina lies due west of Buenos Aires (Fig. 1). Its western border is the boundary between Chile and Argentina. Its capital is the city of Mendoza, which is the eastern terminus of the narrow-gauge Transandine Railway and the western terminus of the standard-gauge Buenos Aires & Pacific Railroad. Here all freight and all passengers crossing from Buenos Aires to Valparaiso must be shifted from standard gauge to narrow gauge. A change back to standard gauge is necessary at Los Andes, in Chile.

The area concerning which this present paper is written is on the eastern flank of the Andes Range, in the central western part of Mendoza Province, approximately at 69° E. Longitude and 35° S. Latitude. It is about 125 miles south of the city of Mendoza and 650 miles west of Buenos Aires. It is reached by driving by automobile 100 miles west from San Rafael, the nearest railroad town, served by rail from both Mendoza and Buenos Aires.

[1] Presented before the Association at the New York meeting, November 17, 1926. Manuscript received by the editor January 6, 1927. This paper refers to some of the results of an extensive reconnaissance made in the latter part of 1923. For the privilege of publication the writer is indebted to the Sun Oil Company. He is happy to express his gratitude to Mr. J. B. Eddis, of Buenos Aires, and to Dr. José M. Sobral, director of the Bureau of Mines of Argentine, for their kind assistance in furthering this study.

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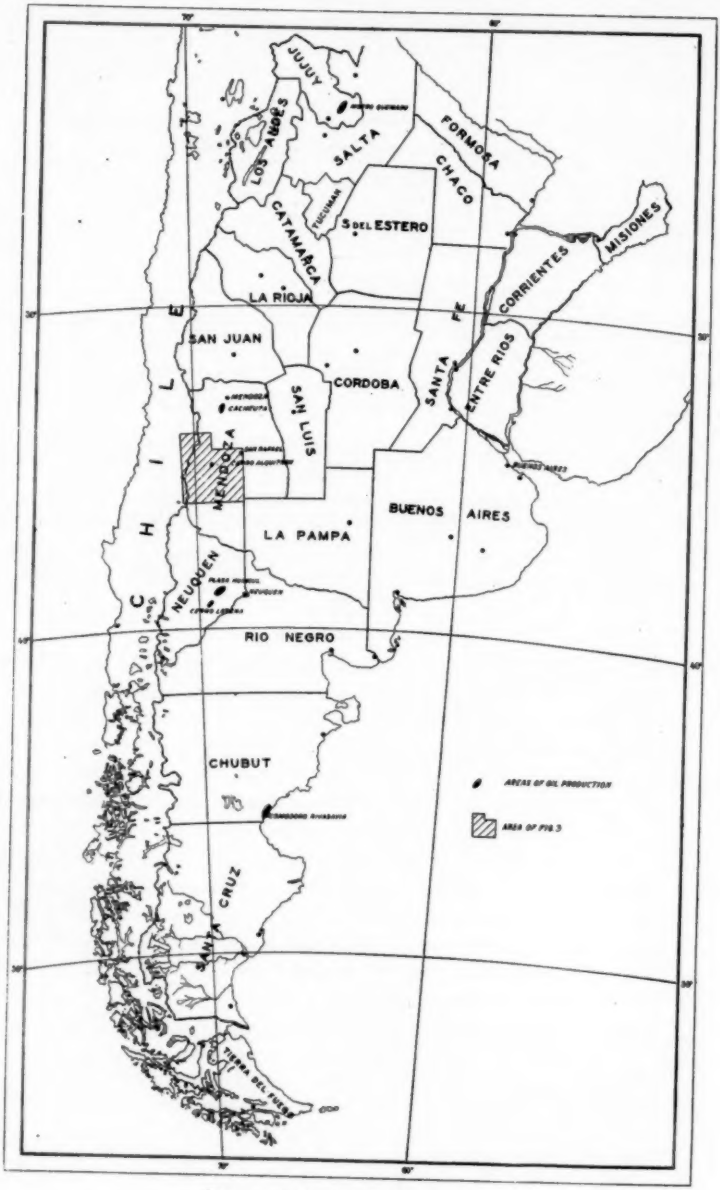

FIG. 1.—Index map of Argentina

Oil-producing districts of Argentina.—The best-known petroliferous district of Argentina is Comodoro Rivadavia. This is in the extreme southeastern corner of Chubut Territory, on the Atlantic coast, about 1,000 miles southwest of Buenos Aires (Fig. 1). Here, in 1925, more than 6,000,000 barrels of oil were produced.[1] The gravity of this oil ranges from 21.3° to 25.4° Bé. It comes from several sands of Senonian and basal Danian age (uppermost Upper Cretaceous),[2] at depths of less than 2,000 feet.

Next in importance to Comodoro Rivadavia is the Neuquen district, situated in the eastern foothill belt of the Andes in the central part of Neuquen Territory (Fig. 1). There are at least two producing pools here, one at Plaza Huincul and the other at Cerro Lotena. The oil has a gravity of 34° Bé. It is obtained apparently from fine clayey sands in the lower part of the Tithonian (Portlandian) (Upper Jurassic). At Plaza Huincul the oil comes from depths of approximately 1,800 feet.[3]

Continuing northward along the eastern borderland of the Andes, the next district which has yielded oil in drilled wells adjoins Cerro Alquitran. Here nine wells had been drilled in 1924. All but one, a dry hole, were within 700 feet of the hill of andesite which is known as Cerro Alquitran. These eight holes were carried to depths between 375 feet and 1,300 feet. Two of them flowed for several years. Oil was obtained from five others. This oil is black, viscous, and asphaltic, with a gravity of about 14° Bé.

Still farther north, at Cacheuta, 25 or 30 miles southwest of the town of Mendoza, several wells have produced oil from different depths, but all except one from less than 2,000 feet. The oil has a high paraffin content. It comes from sandstone just under a 60-foot bed of laminated black, highly petroliferous shale which, by its fossils, is shown to be of Rhaetic (Upper Triassic) age.

The fifth oil district is a belt of country extending through the provinces of Jujuy and Salta into Bolivia, and lying east of the Andes Range. Oil seepages are plentiful and some production has been obtained by drilling (Morro Quemado).[4] The oil varies greatly in character. The two extreme types are a light yellowish oil, having a gravity ranging from 41° to 46°, and a heavy black oil ranging in gravity from 20° to 27° Bé.[5] Two formations have been described as possible

[1] F. T. Ostrander, "Petroleum in Argentina," in "Petroleum Development and Technology in 1925," *Amer. Inst. Mining and Metallurgical Engineers* (New York, 1926).

[2] Dr. Anselmo Windhausen, "Lineas generales de la constitución geológica de la región situada al oeste del Golfo de San Jorge," *Boletin de la Academia Nacional de Ciencias en Cordoba*, Vol. 27 (Buenos Aires, 1924), pp. 167–320.

[3] E. Hermitte, "Memoria de la Dirección General de Minas, Geología e Hidrología. Correspondiente al año 1920," *Anales del Ministerio de Agricultura de la Nacion*, Vol. 15 (Buenos Aires, 1921), No. 3. (See, in particular, pp. 99–108, and the graphic log of Well No. 2 at Plaza Huincul.)

[4] C. M. Hunter, "Oil Fields of Argentina," *Jour. Inst. Petroleum Technologists*, Vol. 10 (London, 1924), pp. 829–53.

[5] Stanley C. Herold, "Economic and Geologic Conditions Pertaining to the Occurrence of Oil in the North Argentine–Bolivian Field of South America," *Trans. Amer. Inst. Mining and Metallurgical Engineers*, Vol. 61 (New York, 1920), pp. 544–64.

sources for these oils. One is a series of Devonian petroliferous shales, and the other is a series of calcareous and siliceous shales and dolomitic beds known collectively as the "Dolomitic Limestone," classified as Cretaceous.[1]

With reference to the structural conditions in these five districts, at Comodoro Rivadavia the oil comes from broad flat domes; at Cerro Alquitran it is obtained from sands tilted up against an intruded igneous plug; and in the other three areas, all in the eastern foothills belt of the Andes, the producing folds are rather strong and relatively long and narrow; dips may be as high as 50° or 60°, or even more; and faulting is common.

FIG. 2.—View looking east from pre-Cordilleran escarpment just west of San Rafael

Physiographic features of central-western Mendoza.—We have already mentioned San Rafael as the point where one who is traveling westward in central Mendoza must leave the railroad and continue by automobile. This town is at the western margin of the great eastern and central Argentine plains which, starting near sea-level in the district of northeastern Buenos Aires Province, gradually rise to elevations between 1,500 and 2,000 feet.

A few miles west of San Rafael the road begins the ascent of a prominent escarpment, the eastern front of the so-called pre-Cordillera (Fig. 2), which is composed for the most part of ancient sediments, such as quartzites, schists, and hornfels, and felsitic and granitic rocks. The summit of the escarpment has a relief of nearly 2,000 feet above the central Argentine plain.

[1] Robert Anderson, "Observations on the Occurrence and Origin of Petroleum in Argentina and Bolivia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (Chicago, 1926), pp. 853–59, particularly p. 855. The substance of this paper was first published in *Actas y Trabajos del Primer Congreso Nacional de Química*, Vol. 4, Sección Tecnica (Buenos Aires, 1921), pp. 23–31.

From the crest of this escarpment a broadly rolling plateau and high plains belt stretches westward nearly 100 miles. In the eastern third of this belt, rocks of the pre-Cordilleran complex are exposed in numerous outcrops. Westward these disappear under a mantle of Tertiary beds and younger sands and gravels which continue to the base of the Andes foothills.

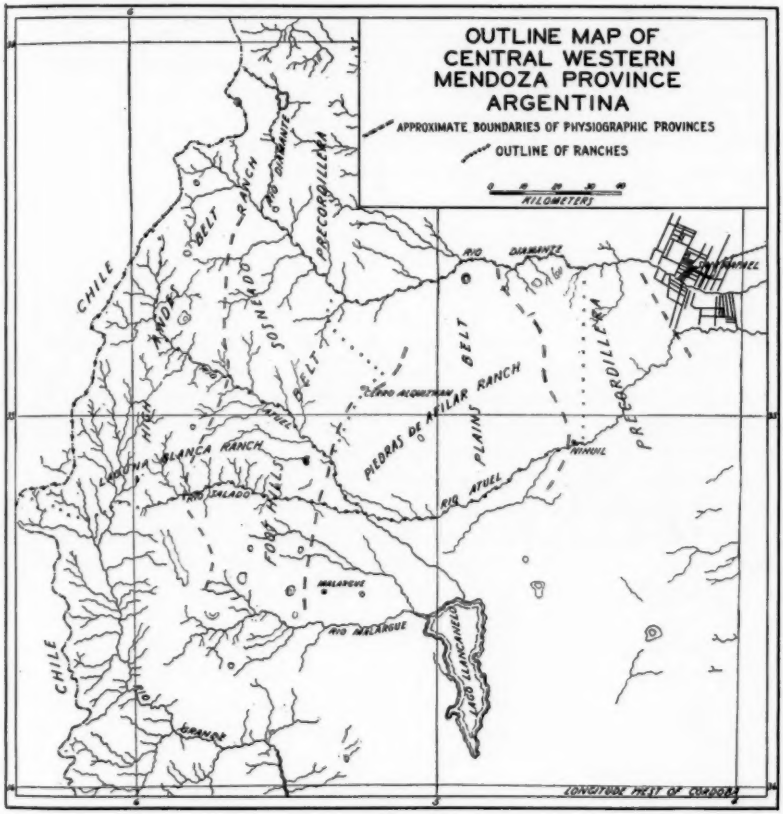

FIG. 3

The foothills belt includes here the area of particular interest for petroleum. It is fairly rugged, being characterized by ridges which trend somewhat east of north, roughly parallel to the main Andes Range. The topographic relief ranges from 300 and 600 feet in the eastern part to 3,000 and 4,000 feet in the western part. The summits of the hills are at higher and higher altitudes toward the west. Major streams which cut across the foothills belt, transverse to the trend of the ridges, are the Diamante, Atuel, Salado, and Malargue rivers (Fig. 3).

The foothills belt passes almost imperceptibly into the province of the high Andes, within which the relief may be as much as 9,000 or 10,000 feet, and some of the peaks rise to heights of 17,000 feet above sea-level. Many of the most lofty peaks are volcanic cones.

STRATIGRAPHY

Sedimentary rocks.—The stratigraphy of different localities within the eastern Andean Province has been described by several field investigators,[1] but as far as we have been able to learn, none has explained in detail geological conditions between the Atuel and Diamante rivers. As a result of our reconnaissance work in this district, we have formulated the following stratigraphic table. To facilitate reference to these formations, we have designated them by local names, usually chosen from places where they are well exposed.

The Matilda series, of Liassic age, is so named because it is widely exposed near the "Matilda Mine," an asphalt seepage, in the foothills on Laguna Blanca Ranch, not far south of the point where Arroyo Blanco unites with Atuel River (Fig. 4). In its lower part it consists chiefly of alternating, rather hard, flesh-colored to yellowish-brown, well-bedded platy sandstones and thin shales, thin coaly seams, and thin soft greenish sandstones. On account of the frequent changes in the hardness of these beds, the hillsides on which they outcrop have a ribbed appearance, the more resistant layers bringing into conspicuous relief the intricate crumpling to which the series has been subjected (Fig. 5). In the upper part of the Matilda group there is relatively less sandstone and more shale than in the lower. There are also a few thin beds of sandy limestone. Fossils of Liassic age are plentiful, especially in the Upper Matilda.

The Matilda series is widely exposed in the western foothills belt. Its easternmost outcrops are just west of Arroyo Blanco, just west of the junction of Arroyo de la Manga and Arroyo de los Tabanos, and so on northward.

The Chilca series is well exposed near the mouth of Arroyo de la Chilca. It rests conformably on the Matilda series. It consists principally of hard black slaty shales, with a few intercalated beds of dark gray sandstone and conglomeratic limestone. It gives an odor of bituminous matter, when heated, but yields no test for petroleum. It contains round or oval smooth gray limy concretions. It may contain lenses of gypsum. Near its base it contains a few fossils like some of those in the Matilda. It may therefore be of Liassic age, but insufficient species were found to settle its classification.

The Manga sandstone, named from its prominent occurrence on Arroyo de la

[1] See especially the following: Pablo Groeber, "Estratigrafía del Dogger en la República Argentina," *Direción General de Minas, Geología e Hidrología*, Boletin 18, Serie B (Geología), Buenos Aires, 1918. He publishes a good bibliography of the earlier writings.

Kirtley F. Mather, "Front Ranges of the Andes between Santa Cruz, Bolivia, and Embarcación, Argentina," *Geol. Soc. of Amer. Bull.* 33 (1922), pp. 703–64.

Anselmo Windhausen, "Ensayo de una clasificación de los elementos de estructura en el subsuelo de la Patagonia," *Boletin de la Academia Nacional de Ciencias de Córdoba*, Vol. 25 (Buenos Aires, 1921), pp. 125–39.

Manga opposite the mouth of Arroyo de los Tabanos, probably rests unconformably on the Chilca. It is yellowish in color, rather friable, with a tendency to be conglomeratic. It is excellently cross-bedded.

TABLE OF FORMATIONS

SEDIMENTARY

Post-Tertiary	Recent alluvium, wind-blown sands, plains gravels, valley gravels, valley tuffs, and glacial deposits	
Tertiary	Ranch-house conglomerate. 6,000 ft. or more thick	
——————Probable unconformity——————		
Eocene or uppermost Upper Cretaceous (Danian)	Ramadas series. 3,000–3,500 ft.	
Cretaceous	Salas sandstone series. 1,500–1,800 ft.	
	Salas limestone group. 200± ft.	
Lower Cretaceous (Neocomian)	Diamante limestone. 40–800± ft.	
Jurassic	Portlandian	Ammonite shale. 400–900 ft.
	?	Blanco sandstone. 600–1,000 ft.
	Oxfordian(?)	Tabanos group. 800–1,000 ft.
	?	Manga sandstone. 250–350 ft.
	——Probable unconformity——	
	?	Chilca series. 800–1,200 ft.
	Liassic	Matilda series { Upper, 500+ ft. Lower, 900+ ft.
Pre-Jurassic	Not studied. Probably Triassic in part	

IGNEOUS

Late Tertiary to Recent	Valley lavas and associated volcanoes
Probably early Tertiary	Andesitic flows, volcanoes, and intrusive bodies
Pre-Jurassic (age uncertain)	Granite gneiss

The Tabanos series was named from Arroyo de los Tabanos. It includes a lower shale member with thin sandstone beds near the base, a middle gypsum member, and an upper shale member. None of these was closely examined by the writer. No fossils were discovered. The gypsum, which may be as much as 600 feet in thickness, probably corresponds to Groeber's "principal gypsum,"[1] assigned

[1] Pablo Groeber, "Estratigrafía del Dogger en la República Argentina," *Dirección General de Minas, Geología, e Hidrología*, Boletín 18, Series B (Geología), Buenos Aires, 1918.

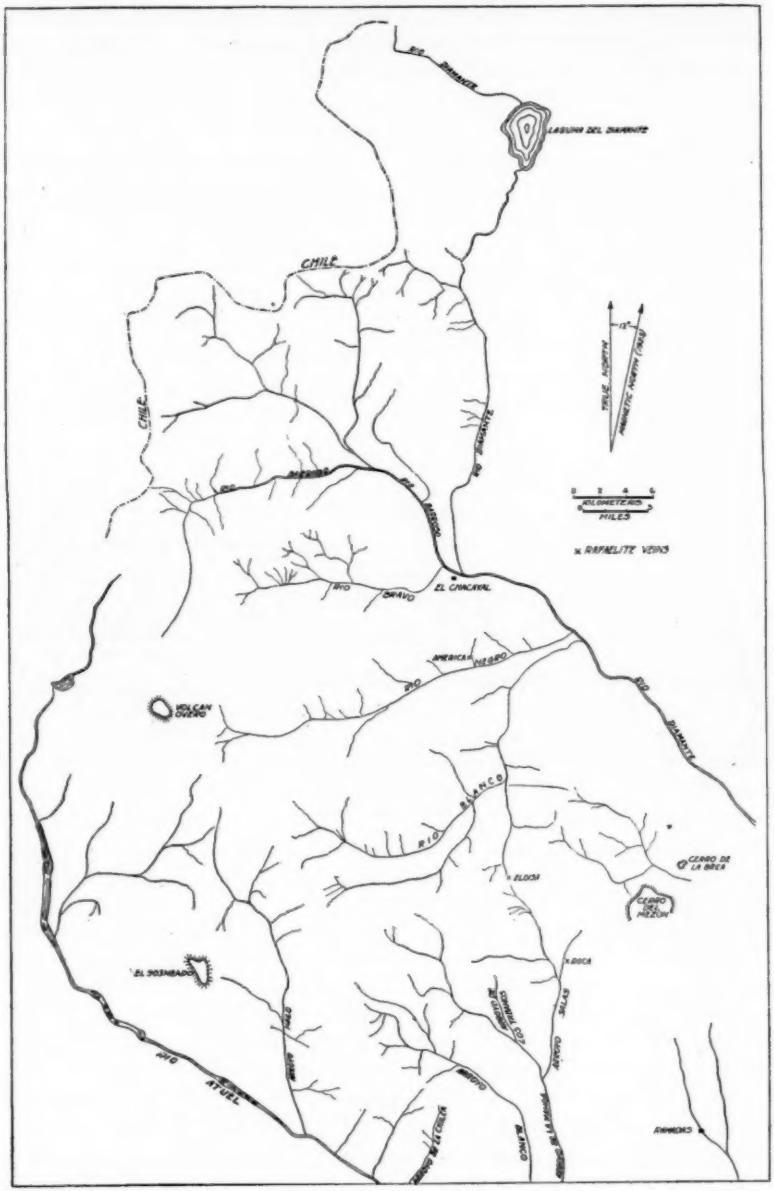

FIG. 4.—Outline map of the region between the rivers Diamante and Atuel (see Fig. 3)

by him to the Oxfordian division of the Jurassic. This gypsum is a very conspicuous feature for many miles along the eastern Andes slope.

Next above the Tabanos series is the Blanco sandstone, named from Arroyo Blanco. This rock is in many places conglomeratic. In its more sandy phases it is exquisitely cross-bedded. Its color is reddish, but with a deep brownish or purplish tone which causes it to appear chocolate-colored at a distance. In places this deep reddish hue is mottled with a lighter flesh color. No fossils were found. Neither the age of the Blanco sandstone nor its exact relation to the underlying Tabanos was determined.

The Ammonite shale is dark gray to black, rather soft, weathering light gray. It contains many pelecypods and cephalopods of Portlandian affinity, and in many

FIG. 5.—Folded "Matilda formation," south side of Atuel River above the mouth of Arroyo de la Chilca.

places rounded limy concretions, similar to those in the Chilca shale. Toward its top the series acquires a limestone facies, layers of yellowish-gray (weathered) well-bedded limestone being of common occurrence. Toward its base the formation includes thin sandstone beds. In other words, it grades down into the Blanco sandstone, seemingly with conformable relations.

Chips of the Ammonite shale, when placed in ether or chloroform, gradually yield enough oil to discolor the fluid. When heated, the rock gives off very strong petroliferous fumes. Quantitative ignition tests demonstrated that fragments of the shale suffered a loss of 18 per cent by weight, this loss probably being chiefly petroliferous material. Fresh fractures of the shale exhibit an oily iridescence, and the cephalopods, when broken open, may show a solid petroleum residue of Grahamite or Rafaelite.[1] This is interesting, for it indicates, since the Ammonite shale

[1] F. H. Lahee, "Note on the Origin of Petroleum," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8 (1924), pp. 669–71.

contains no observed plant remains but instead a profusion of animal remains, that the petroliferous matter had its source in these animal remains.

The relations between the Upper Jurassic and Lower Cretaceous are uncertain. Apparently they are conformable. Above the limy phase of the Ammonite shale is more shale which may still be of Portlandian age. This is directly overlain by a white massive coarse limestone full of shells of *Exogyra couloni* Coquand, of Neocomian age. This we have called the Diamante limestone because it attains a

FIG. 6.—Scarp of "Diamante limestone" forming south canyon wall of Diamante River east of Cerro de la Brea. The cliff is 60 or 70 feet high.

FIG. 7.—Agglomerate in upper part of "Ranch-house conglomerate formation" (not far east of Arroyo de la Manga).

thickness of several hundred feet where it outcrops on the south wall of the Diamante canyon (Fig. 6). Southward from the Diamante River, this limestone rapidly thins until, in the vicinity of Arroyo de la Manga, it is only 40 feet thick. At its outcrops near the Diamante it contains an assemblage of huge shells. Cephalopods were measured as large as 2 feet in diameter. Specimens of *Trigonia transitoria* were seen 7 inches long. The lime here contains much sand. In the Diamante Canyon it is seen to rest, not on shale, but on a fine conglomerate which has pebbles of porphyry, felsite, and gneiss. This conglomerate lies unconformably upon a basement of granite gneiss, hornfels, slate, and felsite porphyry. The Jurassic is entirely missing, probably because it was not deposited here. This basement

complex belongs to the pre-Cordilleran massif, which, north of the Diamante River, forms a range of high mountains running nearly due northward. This range has its southern termination at the Diamante River about 50 miles west of the pre-Cordilleran scarp near San Rafael (see p. 264), and directly north of the main part of the "foothills belt," as previously described.

In the region of Arroyo de la Manga this limestone is overlain by about 100 feet of shale, and above this, a hard, dense, platy limestone with practically no visible fossils, locally with fine banding and with some oölitic layers, and with more or less chert in small lumps and thin layers. In some localities there are two or three distinct beds of this platy limestone, and in places gypsum may be associated with it or may actually take its place in the series. As this group is rather conspicuously exposed in the upper part of Arroyo Salas, we have designated it the Salas limestone group.

Next above this group is a thick series of red sandstones and conglomerates, which we are calling the Salas sandstone series. The red is almost a brick-to-purplish red, not as dark as that of the Blanco sandstone. Cross-bedding is rather indistinct. The conglomerate layers contain pebbles of quartz-porphyry, felsite, and quartz, but nowhere do they contain andesite, nor were there found grains of clastic hornblende, which are common in the Tertiary Ranch-house conglomerate (see later). No fossils were found in the Salas series.

Overlying the Salas series is a great series, from 3,000 feet to 3,500 feet thick, named the Ramadas series. It is divisible into three members. The lowest and the uppermost resemble each other. They consist of a variegated alternation of soft, thin grayish, yellowish, and brownish sandstones, grayish, greenish, and maroon shales, some red sands and shales, greensands, and white dolomitic layers. The middle member contains two to eight or ten relatively thin beds of fossiliferous limestone with intercalated shales similar to those in the lower and upper members. These limestones are of two distinct types. One is white and carries shells of a small oyster (?), whereas the other is yellowish, porous, and sandy, containing shells of *Turritella* and *Venericardia*. Wherever these two limes were studied by us the white lime was below the yellow or *Turritella* lime.

Dr. John B. Reeside,[1] of the U. S. Geological Survey, writes as follows concerning the fossils from these limestones:

> The fossils belong to the fauna of the beds called by some of the Argentinian geologists the Roca beds, which by others are united with the Salamanca beds and designated the San Jorge formation. . . . . Some of the geologists who have studied the matter both in the field and laboratory place the fossils in the latest Cretaceous; others put them in the Tertiary without reservation. To one who has only the discussions of the stratigraphy and the illustrations of the fossils as a basis, the Tertiary assignment seems more logical than Cretaceous.

[1] The writer is glad to express his sincere thanks to Dr. Reeside for examining and classifying a collection of about fifty specimens from the Argentine. The conclusions presented in this paper as to the age of the formations depend largely on Dr. Reeside's determinations.

Since these limestones are in the middle of the Ramadas series, the age of the entire series may be stated as probably lower Eocene.

There is a marked unconformity between the Ramadas series and the next overlying formation, which we have called the Ranch-house conglomerate because of its exposures just behind the main dwelling house on El Sosneado Ranch. In many places this conglomerate and the Ramadas group look as if they were conformable, but there are some localities where this contact may be seen to cut across the Ramadas beds.

The Ranch-house conglomerate is reddish or pinkish, especially in its lower portion. Its upper part is gray. It contains many pebbles and boulders of andesite and also of the Salas and Blanco sandstones, the Salas limestone, and the concre-

FIG. 8.—Northeast side of Cerro Alquitran, an andesite plug. Extensive seepages of asphalt are situated just below the steep slope.

tions from the Ammonite shale. Its reddish color seems to be due to pebbles and grains of the Salas and Blanco red sandstones. In its matrix are chips and splinters of hornblende such as occurs in the andesite pebbles. This formation is very thick (probably 6,000 feet or more), poorly bedded, generally loosely cemented, and in many places very coarse. Its upper part, in some beds, is almost an agglomerate, made of andesitic débris ranging from finely pulverized matter to great angular blocks several feet across (Fig. 7). The whole series is apparently of terrestrial origin, chiefly fluviatile.

Igneous rocks.—We shall not attempt to describe the igneous rocks of the basement complex on which the Jurassic and younger rocks rest.

Of much later date are the andesites, or rocks of allied character, which were intruded into, and through, the Jurassic and Cretaceous strata in the form of plugs,

sills, and dikes. Among these plugs the following are important: Cerro Alquitran (Fig. 8), Cerro de los Buitres, Cerro de la Laguna Seca, Cerro de la Brea (Fig. 9), and Cerro de la Mala Dormida. The igneous rock composing these plugs is gray. It has a very fine matrix with phenocrysts of plagioclase and hornblende. Remnants of flows of the same material occur high on some of the divides.

Within the present valleys there are at least two periods of post-glacial vulcanism represented in basaltic flows and beds of volcanic tuff which have been dissected by subsequent river erosion. Patches of these flows still remain in several of the valleys, notably those of the rivers Diamante, Barroso, Negro, and Blanco, and of Arroyos Malo, Blanco and de la Manga (Fig. 4). Apparently these flows descended the valleys radiating from Volcan Overo.

FIG. 9.—The andesite plug, Cerro de la Brea, viewed from the south. The cliff on the right is several hundred feet high.

In reviewing the stratigraphy of this region, the reader will have noted (1) that, from the Jurassic up to the earliest Eocene, the formations indicate many changes between near-shore marine conditions, and near-shore land conditions of deposition, and (2) that only one of these formations, the Ammonite shale, now has evidences of carrying any considerable amount of petroliferous matter. There is no proof that the Matilda series or the Diamante limestone has served as a source bed, although each is abundantly fossiliferous.

STRUCTURAL GEOLOGY

Folds and faults.—The fact that the mountain summits gradually become lower eastward in the Andes Province has already been mentioned. Similarly, although the strata are highly folded and faulted, there is an average eastward inclination

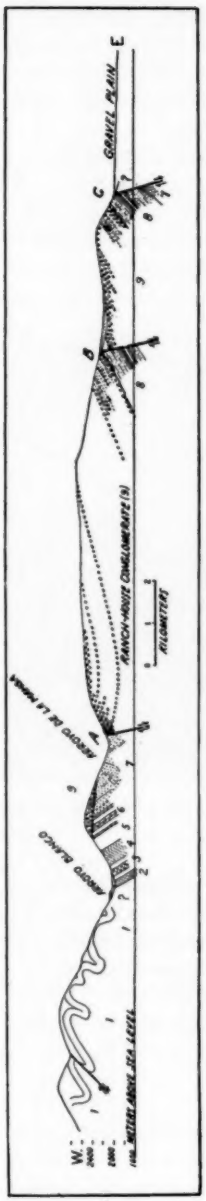

FIG. 10.—Generalized vertical cross-section across the "foothills belt" north of Atuel River (approximately along south edge of Fig. 4): *A*, Manga fault; *B*, Mezon fault; *C*, Ranch-house fault; 1, Matilda and Chilca series; 2, Manga sandstone; 3, Tabanos group; 4, Blanco sandstone; 5, Ammonite shale; 6, Diamante limestone; 7, Salas sandstone series; 8, Ramadas series; 9, Ranch-house conglomerate.

of the formations, so that progressively older sedimentary series are exposed westward. Within the foothills belt (Fig. 3), Triassic and Liassic strata are exposed, even at high elevations, in the western part, Jurassic and Cretaceous beds in the central part, and Cretaceous and Tertiary strata in the eastern part (Fig. 10).

The complexity of the deformation seems to be greater in the older beds. Thus, the Liassic strata are in many places very highly contorted, with all the characteristics of having suffered collapse. The Upper Jurassic and Cretaceous beds are strongly folded, even to the point of overturning passing into thrust-faulting, but they are seldom if ever as much twisted and crumpled as the Liassic strata. The Eocene beds, for the most part, seem to have been tilted and block-faulted, with very little strong bending except that due to local drag attending faulting.

Figure 10 is a composite cross-section of these structural conditions in the southern part of El Sosneado Ranch. The folding shown in the Matilda-Chilca group (1) is not actual, but is representative of the degree of deformation exhibited by these formations. Between these Liassic beds and the great downthrown block of the Tertiary Ranch-house conglomerate, the Jurassic-Cretaceous series is bent in a double fold. Northward, in the upper valley region of Arroyo Salas, this fold becomes overturned toward the east. Still farther north, near the Diamante River, there is repeated folding in this series.

As may be seen from the section (Fig. 10), the three major faults (*A*, *B*, and *C*) have large displacements. The westernmost (*A*) runs up the valley of Arroyo de la Manga. It may be called the Manga fault. It was not closely studied, nor was it traced far northward. Its presence is inferred partly because of the absence of the thick Ramadas group and partly because of the very steep local dips at the western exposures of the Ranch-house conglomerate.

Fault *B*, known as the Mezon fault, is well

defined just south of Cerro del Mezon. It is suggested, farther south, by an apparent repetition of the lower part of the great Ranch-house conglomerate.

Fault *C*, or the Ranch-house fault, determines the eastern front of the foothills belt. This fault is entirely concealed, but there is good evidence for its existence, first, in the truncation of the westward-dipping Ranch-house conglomerate and underlying Ramadas series, and second, in the fact that fairly recent slipping, directly in line with the base of the foothills front, has resulted in a drop of 20 or 25 feet in the upper level of the outwash gravels of the Atuel River.

An important fault, which strikes approximately east and west, marks the place where the Diamante River comes out of a steep-walled canyon in the pre-Cordilleran complex a few miles east of Cerro de la Brea. The downthrow is on the south (Fig. 11). The Diamante limestone and associated beds are dragged down toward the fault on the upthrown side. The displacement is enough to bring this limestone, on the upthrown side, opposite beds in the Ramadas series on the down-thrown side. Further reference to this fault is made on p. 276 in connection with a large asphalt seepage.

FIG. 11.—Drag of strata into the Diamante fault (looking northeast).

Intrusive plugs.—In early Tertiary times intense igneous activity in this region resulted in the intrusion of several volcanic necks or plugs of andesite. Some of these necks must have reached up to the ground surface of that period, for lavas of very much the same kind of rock now cap some of the divides, and boulders and smaller débris of andesite are very plentiful in the Ranch-house conglomerate. It is our opinion that the time of this volcanic activity corresponded with the time of deposition of the Ranch-house conglomerate, although probably the volcanic outbursts were intermittent.

The plugs clearly cut across strata of the Salas and Ramadas series. The act of intrusion seems to have bent upward and literally torn the strata, so that now they dip outward from the plugs, at high angles near the contact, but with diminishing inclination away from the contact (Fig. 12).

PETROLEUM

Seepages.—Seepages of black tarry oil are plentiful in the foothills belt from the Diamante River southward at least as far as Rio Malargue. Those seen by the writer are indicated on the maps (Figs. 3 and 4).

A few hundred feet northwest of Cerro de los Buitres, an andesite plug, is a seepage of asphalt. Its relations to the structure and formations could not be determined. It may be on a fault or a fracture zone associated with the plug.

At Cerro Alquitran (Fig. 8) there are large asphalt seepages on the west, north, and east sides of the hill. Also, on a fracture zone within the outcrop of the andesite itself there is a small seepage of asphalt which comes up with water. The peripheral seepages are undoubtedly escaping through fractures associated with this plug.

About two miles northwest of Cerro Alquitran is an extensive asphalt seepage (Paloma) which, although banked up against an andesite mass, seems to be connected with a pronounced line of cross-faulting.

FIG. 12.—Ramadas beds dipping eastward from the Cerro de la Brea plug, which is just to the left (west) of the picture.

On the steep east face of Cerro de la Brea (Fig. 9) there are patches of sandstone, with vertical dip, which have not yet been removed by erosion. These show signs of impregnation by asphalt. A few hundred yards southwest of this hill is a spring of sulphur water with which a little asphalt is ascending. This spring seems to be on a line of faulting which trends about S. 20° W. from the eastern side of Cerro de la Brea.

The seepages at Cerro Alquitran, Paloma, and Cerro de la Brea are probably located on exposures of the Salas and Ramadas series. Three miles east of Cerro de la Brea a large asphalt seepage is situated almost in line with the big Diamante fault (see p. 275). The surface beds are probably not far above the Diamante limestone, which, it will be remembered, not more than half a mile to the northeast, rests unconformably on the pre-Cordilleran basement complex.

Finally, at Mina Matilda, south of the Atuel, near the point where this river is joined by Arroyo Blanco, water, together with a little asphalt, escapes along a transverse fault which here displaces the Matilda formation.

Rafaelite veins.—There are several localities where a solid petroleum compound, known as rafaelite,[1] is encountered in the shape of veinlike sheets. These no doubt represent the fillings of old channels through which fluid petroleum once moved. They may have led to seepages at higher levels, now eroded. The most important occurrences of these veins are at Mina Eloisa, Mina Roca, and Mina America. The last was not seen by the writer. At Mina Roca and Mina Eloisa (in the upper valleys of Arroyo Salas and Arroyo de las Minas) the veins are vertical or steeply inclined and their strike is nearly at right angles to the strike of the beds. In both places the country rock is the red Salas sandstone which has been bleached to a grayish color in the vicinity of the rafaelite. The reduction of the red iron oxide in the sandstone was probably accomplished through the agency of H_2S associated with the petroleum.[2]

West of El Chacayal, rafaelite veins were seen intersecting a thick contorted mass of gypsum. The age of this gypsum was not surely determined. Presumably it belonged in the Salas limestone group.

Source of the petroleum.—From the foregoing brief review of the oil seepages and rafaelite veins in this region, the reader will notice that all, with one exception, are within the belt of country underlain by the Ammonite shale, shown to be of Portlandian age. This one exception is the seepage at Mina Matilda, where the outcropping strata belong to the Matilda series of Liassic age. Furthermore, all are escapes along faults or fracture zones. These relations strongly suggest that the petroleum had its origin in the Ammonite shale. The case of Mina Matilda may be accounted for by the fact that the fault here is transverse to the strike of the beds, so that the oil may still be coming from the Ammonite shale farther east where it is buried. The asphalt seepage near Diamante River, east of Cerro de la Brea, may be ascending from the Ammonite shale on the downthrown side of the Diamante fault. Although, on the upthrown side of the fault, this shale is missing between the Diamante limestone and the pre-Cordilleran basement complex, it probably wedges in by overlap within a comparatively short distance to the south, in which direction the whole stratigraphic prism thickens rapidly.

Origin of the petroleum.—If the Ammonite shale is the source from which the rafaelite, the seepage asphalt, and the oil of Cerro Alquitran have come, we may conclude that the mechanical action of faulting, together with some heat due to friction or to depth of burial, or the heat and squeezing and shearing attendant upon the intrusion of the andesite plugs, or perhaps both processes, have functioned

[1] This substance is light in weight, glossy black in color, very brittle, and with a tendency toward an irregular cleavage. It ignites readily, burning with a yellow flame and giving off a strong petroleum odor.

[2] Gail F. Moulton, "Some Features of Red-Bed Bleaching," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 304–11.

in the derivation of the petroleum from its mother-substance in the shale. The problem of the origin of the oil in this district has a particular interest because the factors of source rock and avenue of migration appear to be simple of explanation.

Possible productive structures.—The country which we have been describing is one in which the geologic structure is complicated. Folds are strong; dips are steep and in places overturned; faults have displacements of hundreds or thousands of feet; and there are many intruded igneous bodies. In spite of all this evidence of orogeny and vulcanism, the stratified formations upward from the Liassic are essentially unmetamorphosed. The thin stringers of coal found in the Liassic series have a relatively low fixed-carbon content. We believe, therefore, that within this region the following varieties of structure have a chance of yielding oil: (1) well-developed anticlines of orogenic origin; (2) domes above intruded igneous plugs and laccoliths; (3) upthrown fault blocks where the fault strikes parallel to the strike of the beds, the upthrown side is in the direction down the dip of the beds, and drag into the fault or fault gouge or shale in the downthrown block serves as a seal for the retention of oil; and (4) porous beds tilted up against igneous dikes or plugs and sealed by shale or by projecting irregularities of the igneous body. It is likely that all of these types are represented in the western Mendoza region.

OIL AND GAS POSSIBILITIES IN THE ARKANSAS OZARKS[1]

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ABSTRACT

Analyses of coals from northern Arkansas have made it possible to construct a new isocarb map of the entire Ozark region. This map throws light upon the oil and gas possibilities of the Arkansas Ozarks, an area which has been condemned by most geologists and avoided by the larger companies. A complete stratigraphic table for northern Arkansas is included, and the depth to the crystalline basement is indicated by well logs. A consideration of possible source and reservoir rocks, surface indications, and structural conditions leads to the conclusion that the gas possibilities are fairly good. Oil also may be obtained, but commercial production is not probable, and large pools are practically impossible.

INTRODUCTION

The Arkansas Ozarks for a number of years have received sporadic attention in the search for new areas of possible oil and gas production. As early as 1884 oil and gas seeps in the vicinity of Fayetteville attracted considerable interest, but the Arkansas State Geological Survey, in its *Annual Report for 1888*, condemned the entire region. This unfavorable valuation by the competent and well-known "Branner Survey," coupled with the lack of transportation facilities in the area, was enough to discourage exploration, even in the face of rather promising surface indications. Since 1915 the knowledge that coals just east of Fayetteville run higher than 65 per cent fixed carbon ratio has no doubt served as an additional reason for delaying prospecting by strong organizations.

These adverse conditions, on the other hand, have been no great deterrent to wildcatting. Many local companies have been organized, considerable land has been leased, and some wells have been drilled. In these projects geologic advice usually has been incompetent, unreliable, or entirely wanting; and the financial backing has always been small. For these reasons even the completed wells cannot be regarded as fair tests of the area's oil and gas possibilities.

GENERAL GEOLOGIC AND GEOGRAPHIC FEATURES

Location.—The Arkansas Ozarks are located in the northwestern and north-central parts of the state (Fig. 1). The uplands continue uninterruptedly into Missouri on the north, and into Oklahoma on the west. On the east they are bounded roughly by Black River, in whose neighborhood they descend to the Mississippi Lowlands, and a nearly straight east-west line marks their boundary with the Arkansas Valley on the south.

[1] Manuscript received by the editor October 25, 1926.

[2] Introduced by K. F. Mather.

Topography.—Although this entire area is usually designated as the Ozark region, it may be considered as three definite physiographic divisions, of which only the two northern sections are parts of the true Ozark Plateau. The southern part, which is also a plateau, though higher and more deeply dissected, is called the Boston Mountains.

The Ozark Plateau extends along the northern boundary of the state in a narrow, irregular strip which averages 40 miles in width. This belt is made up of two divisions. The northern and lower of the two, which is called the Salem Plateau,

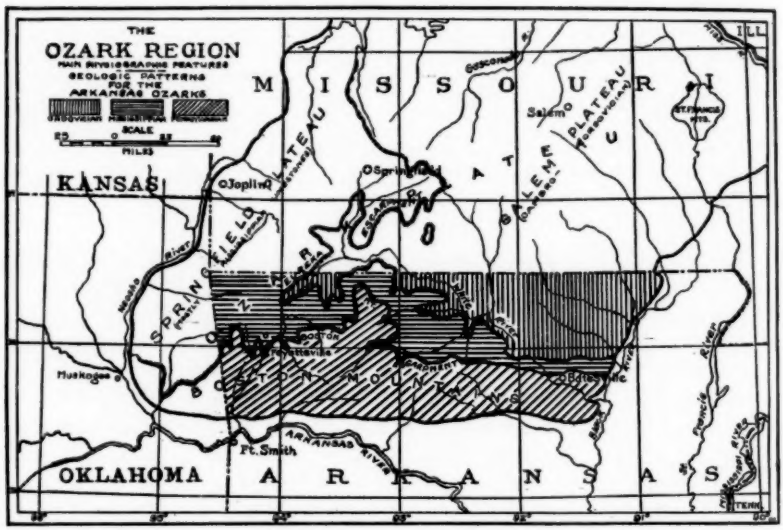

FIG. 1.—A sketch map of the Ozark region showing physiographic divisions and escarpments. The generalized geologic map, drawn for the Arkansas Ozarks only, gives the location of the area under discussion.

is deeply cut by stream erosion, and presents a very rough topography. The tops of the higher ridges and hills, however, attain the same general level, in spite of the fact that its dissected surface has been developed on the truncated edges of a number of formations. The surface rocks are almost entirely Ordovician in age. The major portion of the Salem Plateau of Arkansas lies in the northeast part of the area under discussion, but the upland also extends into Carroll and Benton counties along White River and its tributaries.

Resistant cherts and limestones of Mississippian age form the sinuous, north-facing Eureka escarpment, which separates the Salem Plateau from the higher Springfield Plateau on the south (Fig. 1). The scarp reaches a height of 400 feet in the vicinity of Eureka Springs, but toward the east it becomes less well-defined, and finally, north of Batesville, it is insignificant. Most of the Springfield Plateau

stands between 1,000 and 1,500 feet above sea-level, but its surface on the average is less rough than that of the Salem Plateau. Nevertheless, numerous canyon-like valleys do occur, particularly near the southern boundary of the upland.

The Boston Mountains rise above the Springfield Plateau in a second, and more prominent north-facing escarpment, which attains a height of 800 feet. Viewed from the Springfield Plateau on the north, this escarpment appears to be a uniform, even-topped wall. In reality it is very irregular, for many outliers of the Boston Mountains stand on the plateau, and streams serrate the trace of the scarp with their valleys. The southern slope of the mountains to the Arkansas Valley generally is less precipitous, but in places it descends abruptly and is broken by many ravines. The mountainous area extends from the valley of Neosho River, near Muskogee, Oklahoma, eastward nearly to the junction of White and Black rivers, a distance of more than 200 miles. It is 65 miles across in its greatest north-south extent, but its average width is only about half this distance.

The mountain tops, in general, are capped by the resistant Winslow formation of Lower Pennsylvanian age. They all stand at about the same level, forming a greatly eroded tableland approximately 2,200 feet high; but a few monadnocks, which reach a height of 2,400 feet, are found on the north. Gorges 500 to 1,500 feet deep, with steep ridges and jagged spurs between, are common enough to warrant the application of the term "mountainous" to this highland region.

Stratigraphy.—A generalized map (Fig. 1) shows the areal extent of rocks of Ordovician, Mississippian, and Pennsylvanian age. With minor exceptions, the older formations appear in the north, and younger ones outcrop in the south. Table I gives the general character, thickness, and distribution of these formations. An excellent and somewhat detailed description of the majority of these formations may be found in Folio 202, *U. S. Geological Atlas*.

A glance at the table indicates that few of the many formations recognized in this area are continuous, and that drilling in any one section will reveal a series of rocks quite different from that to be expected in other, and not necessarily distant, districts. The following formations, however, are present throughout (except where they have been removed by erosion): the Winslow and Hale of Pennsylvanian age, the Fayetteville and Boone of Mississippian age, and the Cotter and Jefferson City of the Ordovician series. Cambro-Ordovician limestones have also been encountered in many places by the drill, and although they do not outcrop, they probably are continuous throughout the Ozarks.

General structure.—The general structure of the entire Ozark region is that of an irregular, flattened dome. The strata everywhere dip away from the St. Francis Mountains, of Missouri, which are the eccentric crystalline nucleus of the highlands. The Arkansas Ozarks lie on the southwest edge of this dome, and consequently the rocks here dip toward the south or southwest. The amount of inclination of the beds is slight, particularly near the northern border of the state, where the rocks are essentially horizontal. Dips of one to two degrees prevail in the Springfield Plateau, but these increase to as much as seven or eight degrees in the

TABLE I

Geologic Formations of the Arkansas Ozarks

Period	Formation	Thickness (in Feet)	Character of Rocks	Distribution in Area
Pennsylvanian	Winslow formation	1500+	Black and drab clay shales with thin interbedded platy sandstones. Massive, light-brown to gray, cross-bedded sandstone with white quartz pebbles at base	General south of Boston Mountain escarpment. Thicker toward south
	unconformity			
	Morrow Group: Bloyd shale	0–150	Dark brown to black clay shale	Thickest to southwest in Washington and Crawford counties. Thins to the north and east, where it disappears
	Kessler limestone lentil	(0–10)	Dirty brown, sometimes ruddy limestone, in part conglomeratic	
	Coal	(1)		
	Brentwood limestone lentil	(0–35)	Gray fossiliferous limestone, with some shale	
	Hale formation	50–275	Carbonaceous shale with sandy plates and flaggy sandstones; brown calcareous sandstones and sandy ferruginous limestones	General in south, but thickest in west
	unconformity			
Mississippian	Chester Series: Pitkin limestone	0–100	Massive, gray, fossiliferous limestone	General; thins to the north, thickens to the south
	unconformity?			
	Fayetteville formation	10–400	Black carbonaceous fissile clay shale, with clay-ironstone concretions	General, absent only in north due to erosion
	Wedington sandstone member	(0–150)	Medium to fine grained gray to brown sandstones, in part calcareous; often cross-bedded	Sandstone member thickest in west
	Basal limestones	(0–50)	Fossiliferous limestones (in the west only)	
	Batesville sandstone	0–225	Gray to brown even-bedded sandstone; somewhat calcareous	Developed in east; thin or wanting in west
	Hindesville limestone member		Chert conglomerate, with gray oölitic limestones above	
	Moorefield shale	0–275	Light gray to blue friable shale, with some limey phases	Thickest in east; wanting west of St. Joe
	unconformity			
	Boone limestone	200–450	Gray, crystalline, fossiliferous limestone, with much gray to red chert also fossiliferous; there are at least two oölitic horizons	General north of Boston Mountain escarpment. Basal member usually present, but locally absent
	St. Joe limestone member	(0–100)	Pinkish gray, coarse-crystalline, fossiliferous limestone	
	unconformity?			
	"Chattanooga" (Noel) (Eureka) shale	0–85	Black, fissile clay shale	Thickest in west, and though locally absent, is usually developed. Sandstone member thickest in west
	Sylamore sandstone member	(0–55)	Light brown to white sandstone-phosphatic	
	unconformity			
Devonian	Clifty limestone	0–2+	Gray, compact, sandy limestone	Exposed only in southeast corner of Benton County
	unconformity			
	Penters chert	0–90	Gray blue to dark unfossiliferous chert	Exposed only in the east, in Independence County
	unconformity			
Silurian	Lafferty limestone	0–75	Gray to red, compact, earthy, thin-bedded limestone with few fossils	Exposed only in the east, in Izard County
	unconformity			
	St. Clair limestone	0–100	Pink, fossiliferous, coarse-grained limestone	Absent in west; exposed in the east and northeast
	unconformity			
	Brassfield limestone	0–4	Thin, blue-gray limestone	Absent in west; exposed in Searcy and Independence counties

TABLE I—*Continued*

Period	Formation	Thickness (in Feet)	Character of Rocks	Distribution in Area
	unconformity			
Ordovician	Cason shale	0–20	Platy, gray, calcareous shale	Absent in west; small outcrops in central and eastern portions
	unconformity			
	Fernvale limestone	0–125	Coarse-grained, massive, dark to pinkish gray fossiliferous limestone	Exposed over large areas in northeast. Absent in west
	unconformity			
	Kimmswick limestone	0–50	Even-bedded, fine-grained, massive limestone, light gray to bluish gray in color	Absent in west; exposed in Independence, Izard, and Stone counties
	unconformity			
	Plattin (Izard) limestone	0–250	Dove-colored, even-bedded, fine-grained limestone, which breaks with conchoidal fracture	Exposed over large areas in east; absent in the west
	unconformity			
	Jasper limestone	0–50	Compact, bluish-gray limestone and saccharoidal sandstone	Known only near Jasper, Newton County, in central part of area
	Joachim limestone	0–150	Drab, compact, sandy magnesian limestone, calcareous sandstone, and white friable sandstone	Absent in west; exposed from Newton County east
	St. Peter sandstone	0–175	Massive, laminated, and cross-bedded saccharoidal sandstone	Thin or absent in west; thickest to southeast
	unconformity			
	Everton limestone	0–225	Compact dove-colored limestone with some sandstone	Thickest in central portions; thins to north, east, and west. Sandstone member usually present. Limestone lentil exposures confined to Marion and Newton counties
	Kings River sandstone member	(0–35)	White, friable, heavy bedded sandstone	
	Sneeds limestone lentil	(0–50)	Dark, heavy-bedded, sandy magnesian limestone	
	unconformity			
	Powell limestone	0–200	Gray magnesian limestone, with limestone conglomerate at base in some areas	Absent in west; not always present in east
	unconformity			
	Cotter dolomite	550	Gray dolomite with some chert and a little friable sandstone. Locally green shales appear	General in the north; but thicker in the east
	unconformity			
	Jefferson City dolomite	350+	Gray dolomite and chert	Exposed in northeast Marion County and eastward
Cambro-Ordovician?	*Horizons not exposed in area but reached by the drill.* Mostly magnesian limestone with much sandstone and a little shale	800±	Apparently very similar to the oldest exposed rocks in the area. Probably to be correlated with the Cambro-Ordovician series of southeast Missouri	Not likely to be reached by wells drilled south of Boston Mountain escarpment. Reached by relatively shallow wells on Salem Plateau and by wells moderately deep on Springfield Plateau
	unconformity			
Pre-Cambrian	Red arkosic sediments			Reported as red oil sand in several wells
	Red granite or syenite			Reached by several wells started on the Boone at less than 2,500 ft.

Boston Mountains. Locally there are many flexures which reverse the dip, or make more steeply tilted beds; and faults of moderate size complicate the structure. These smaller structural features will be discussed further under another heading.

Transportation facilities.—Railroad facilities in the Arkansas Ozarks are below average, and roads, in general, are poor. The latter, however, are being improved

rapidly, and it now is possible to travel over most of the area in a light car. The country is still heavily wooded, hence boiler fuel is inexpensive and easy to procure. Roustabout labor is plentiful and cheap.

There are only a few small villages in the Salem Plateau and Boston Mountains, but a number of progressive towns and small cities are located on the Springfield Plateau. These towns are entirely without gas, which hampers their present and future development. Manufacturing for this reason is not now important, but agriculture is flourishing.

OIL DEVELOPMENT

Commercial deposits of oil have not been discovered in northern Arkansas, but small flows of gas have been encountered in almost all of the test wells drilled in this area. A well not more than 300 feet deep 5 miles northwest of Fayetteville has supplied a farmhouse with fuel for approximately 10 years, and wells near Batesville have yielded similar or greater amounts of gas. The gas fields of the Alma district lie about on the border between the Boston Mountains and the Arkansas River Valley.

In one locality or another all the sands shown in Table I have been penetrated by the drill, and several wells have been continued down to the igneous basement. Thus some knowledge of subsurface conditions has been obtained. As this information is not elsewhere available, logs of several wells are given here.

The strata which were encountered in the Wood well, located on the southern slope of the Boston Mountains, have been correlated with formations outcropping to the north, but as no drill cuttings were examined, the correlation is only a tentative one. The Mississippian and older formations are rather definitely placed, but the boundary between the Morrow and the Winslow is not located with any degree of certainty. Where the Morrow outcrops it shows a tendency to thicken toward the south, but in the log given only 104 feet are allotted to this series. A heavy sandstone about 100 feet thick occurs at the base of the Winslow wherever it is exposed. If this sand persists to the location of the well, it is either represented by the 76-foot bed just above the Morrow, as herein placed, or by the 135-foot stratum 591 feet above. If the latter is the case, the Morrow has increased to a thickness of about 700 feet in this locality.

The Sasnakra well drilled 5 miles northwest was logged so differently that, in the absence of the cuttings, there is little information to be gained by a comparison of the two records. Gas was reported in a 40-foot "sand" at 1,240, very wet gas in a 125-foot "sandy lime" at 1,405, and again in a 72-foot "gray gas sand" at 1,998. This horizon may be the equivalent of the 76-foot sand indicated as the tentative base of the Winslow in the Wood well. The Boone evidently was reached in the Sasnakra well at 2,320 as against 2,400 in the Wood test.

This well was accurately logged, so that, while the cuttings were not examined, the correlations given are regarded as being essentially correct. The driller has always maintained that a small well could have been brought in at the showing, but the sand was cased off and the hole carried deeper. This particular well was

RECORD OF THE WOOD WELL, NW.¼ OF NW.¼, SEC. 29, T. 10 N., R. 31 W., CRAWFORD COUNTY, ARKANSAS

		Thickness (in feet)	Depth (in feet)
Surface	Clay	27	27
	Sand	5	32
	Shale	2	34
	Sand	11	45
	Shale	13	58
	Lime	8	66
	Sand	109	175
	Slate	10	185
	Sand	15	200
	Slate	210	410
	Sand	130	540
	Some gas at		492–500
	Slate	40	580
Winslow	Sand	20	600
	Slate	260	860
	Sand	20	880
	Shale	180	1,060
	Sand	15	1,075
	Slate	65	1,140
	Sand	40	1,180
	Slate	125	1,305
	Sand	65	1,370
	Slate	15	1,385
	Sand	135	1,510
	Slate	15	1,530
	Sand	30	1,560
	Shale	200	1,760
Wet gas	Gas sand	45	1,805
	Shale	225	2,030
Base of Winslow	Sand	76	2,106
	Slate	50	2,156
Morrow	Sand	10	2,166
	Shale	44	2,210
	Lime shells	30	2,240
Pitkin	Black lime	45	2,285
Fayetteville	Shale	10	2,295
Wedington	Sand	40	2,235
Fayetteville	Shale	40	2,275
Batesville	Sand and shale	25	2,400
Boone	White lime	315	2,715
Chattanooga	Shale	70	2,785
Sylamore	Sand	10	2,795
Upper Ordovician	Sand, sandy lime, and shale	175	2,970
St. Peter	Soft sand	35	3,005
Salt water		...	.....

located on structure and is one of the few operations in this region which may be said to constitute a test.

This well shows a greater thickness of St. Peter and a smaller interval between this sand and the Chattanooga than is usual. It is possible that some of the sandy limestones above the St. Peter have been logged as "sand" and thus lumped with it. The Sylamore, if present, is much more calcareous than usual, but in all other

RECORD OF THE GRUBER WELL NO. 1, SEC. 24, T. 13 N., R. 30 W., NEAR WINSLOW, WASHINGTON COUNTY, ARKANSAS (SUMMARIZED)

		Thickness (in Feet)	Depth (in Feet)	
Surface	Clay and rock	5	5	
Winslow	Sand and shale	485	490	
Base of Winslow	Heavy sandstone	120	610	
Morrow	Lime, shale, and sand	150	760	
Pitkin	Heavy limestone	60	820	
Wedington	Sand and some lime	65	885	(Oil and gas show at 855)
Fayetteville	Shale	145	1,030	
Boone	Lime and chert	355	1,385	
Chattanooga	Shale	22	1,407	
Sylamore	Sand and some lime	38	1,445	(Sulphur water)
	Lime	5	1,450	

RECORD OF THE WAR EAGLE OIL AND GAS COMPANY WELL, SEC. 13, T. 15 N., R. 26 W., NEAR WITTER, MADISON COUNTY, ARKANSAS (SUMMARIZED)

		Thickness (in Feet)	Depth (in Feet)	
Surface	Sandy gravel	8	8	
Hale	Sand and shale	48	56	(Oil and gas show)
Pitkin	Heavy lime	47	103	
Fayetteville	Shale and sand	166	269	(Oil and gas show —Salt water)
Batesville and Hindesville	Sand and lime	89	358	(Several oil shows)
Boone	Lime, chert, and some sand	268	626	(Some gas)
Chattanooga	Shale	28	654	
Upper Ordovician limes	Lime and sand	78	732	
St. Peter	Hard white sand	216	948	
Lower Ordovician limes	Limes with some sand	127	1,075	(Oil show at 966)

respects the section is a normal one. The remarkable number of "shows" reported seem to be *bona fide*. Wet gas was obtained at the casing head in sufficient quantities to burn with a strong, sooty flame.

The entire log of this well, exactly as reported by the driller, is included here because it indicates the depth to the granite in this area, and throws light on the character of the deeper sediments. Although cuttings cannot be obtained from

RECORD OF THE WELL DRILLED IN THE NE. ¼ OF THE SW. ¼, SEC. 30, T. 15 N., R. 31 W., 1½ MILES SOUTH OF PRAIRIE GROVE, WASHINGTON COUNTY, ARKANSAS

		Thickness (in Feet)	Depth (in Feet)
Surface	Soil	3	3
Fayetteville	Brown shale	7	10
	Brown shale	5	15
	Limestone	6	21
Batesville	Water sand	1	22
Boone	Hard lime or chert	8	30
	Hard lime or chert	10	40
	Hard lime or chert	10	50
	Soft lime or chert	25	75
	Soft lime or chert	15	90
	Soft lime or chert	40	130
	Soft lime or chert	190	320
	Hard Flint	10	330
Chattanooga	Hard black shale	25	365
Sylamore?	Hard limestone	22	387
	Hard sandy shell	23	410
Upper Ordovician limes?	Hard limestone	30	440
	White sandy shale	6	446
	Hard sandy shale	14	460
	White water sand	9	469
	White fine sand	13	482
	Hard white limestone	88	570
St. Peter	Hard white sand	100	670
	White sand	35	705
Everton?	White limestone	160	865
	Water sand—fresh	5	870
Cotter?	Hard white limestone	290	1,160
	Sand shell with pebbles	20	1,180
Jefferson City?	Hard white limestone	100	1,280
	Sand	20	1,300
	Hard white limestone	205	1,505
	Hard coarse sand	45	1,550
	Hard lime shell	25	1,575
	Hard white sand	25	1,600
Base of Jefferson City?	Hard white limestone	80	1,680
	Hard porous lime	10	1,690
	Hard sand lime shell	10	1,700
	Hard white sand	13	1,713
	Hard lime shell	7	1,720
	Hard white sand	50	1,770
	Water sand	15	1,785

RECORD OF THE WELL DRILLED IN THE NE. ¼ OF THE S.W. ¼, SEC. 30, T. 15 N., R. 31 W., 1½ MILES SOUTH OF PRAIRIE GROVE, WASHINGTON COUNTY, ARKANSAS.—*Continued*

		Thickness (in Feet)	Depth (in Feet)
Ordovician or Cambro-Ordovician	White lime, dark streaks	95	1,880
	White sand	90	1,970
	Hard white lime	75	2,045
	White sand—water	25	2,070
	Hard white lime	25	2,095
	White sand—sharp	165	2,260
	Hard white lime	75	2,335
	Blue shale	1	2,336
	Hard white lime	124	2,460
	Blue lime and sand	25	2,485
Precambrian granite	Top of red sand		2,485

this test, the correlations listed are at least roughly accurate to the base of the St. Peter. Below this depth they are frankly guesses, but it is fairly certain that formations outcropping in northern Arkansas extend down to at least 1,600 feet. Thus 800–900 feet of Cambrian or Cambro-Ordovician strata were encountered before the granite was reached. There is a surprising amount of sand in these lower horizons if they have been logged correctly. The "red sand" at 2,485 is a red granitic arkose. Drilling was continued for some distance on into the unweathered rock, but the record is not available. No oil or gas shows were reported.

Another well 5 miles southwest of Bentonville, in Sec. 5, T. 19 N., R. 31 W., was started at about the top of the Boone, and also reached the crystalline rocks. In this test gas was reported from sands at 890, 955, 1,122, 1,342, and 2,225 as well as in limestones at 1,977 and 2,210 feet. An oil show was also reported in a 13-foot "dark sand" just above the "Syenite" which was reached at 2,365 and penetrated to 2,430 feet. The authenticity of these shows may be questioned, especially since oil was also reported from 2,400 to 2,425 feet, apparently well into the igneous basement.

Space does not permit the incorporation of this detailed log. It is in general agreement with the Prairie Grove record, but very different so far as the particulars are concerned. In the Benton County well the St. Peter is much thinner; and the lower sandstones are even more prominent, and not similarly placed.

Showings of oil and gas have been reported from many other tests and from different horizons, but it is not known how reliable these reports are to be considered.

POSSIBILITIES FOR OIL AND GAS

Structures.—As has been pointed out before, reversals of the general south dip are not unusual, and faults are common, particularly in the Boston Mountains. The down-throw side of these faults is almost invariably on the south, and here the beds generally have steep dips and in many places are rather closely folded, though only in the immediate vicinity of the faults.

Several formations may be used as satisfactory key beds for mapping local structure, but regional deformation can best be indicated by structural contours drawn on the surface of the Boone limestone. This formation is the most widespread in the area, but it has suffered erosion before the deposition of the overlying sediments. In addition, the structure as shown on the Boone is not necessarily the structure of the other formations of the area, since few of them are continuous, and none is uniform in thickness. Moreover, post-Boone sediments usually show less deformation, since they have not suffered mid-Mississippian folding. For these reasons only an approximate regional structure can be shown on this bed.

Prominent structural features apparently are not common in the Salem Plateau and are only moderately plentiful in the Springfield Plateau. Where the Boone or the Ordovician limestones outcrop over wide areas, however, the difficulty of mapping structure is great, so that the lack of flexures here may be more apparent than real. On the Springfield Plateau, near the Boston Mountain escarpment, there are several conspicuous structures (notably the Carrolton dome), but they become more common along the crest of the Boston Mountains, in the latitude of Evansville, Winslow, Sunset, Pettigrew, and Witts Springs. A succession of strong southward-dipping monoclines, accompanied by local faulting, appears on the southern slopes of these mountains.

Possible reservoir rocks.—There are several sands in the list of formations given in Table I which may serve as possible oil and gas reservoirs. The sandstones of the Winslow formation yield gas in the Arkansas Valley district, but they lack sufficient covering in all but the southern part of the area under discussion. The Hale formation of the Morrow group is everywhere present, and a number of seeps indicate its possibilities as an oil horizon. The Wedington sandstone member of the Fayetteville also is a potential horizon which is fairly widespread in the west. The Batesville sandstone in the east and the Sylamore in the central part are other sands which might serve as oil or gas containers. The St. Peter is the prominent sandstone among the Ordovician formations, but the Kings River sandstone and the sand in the Jasper limestone are also possible reservoirs. The logs previously cited indicate that even deeper sands and limestones may carry hydrocarbons.

The carbon ratios to be discussed later show a relatively high degree of metamorphism for the Arkansas Ozarks. This metamorphism should be expected to cause low porosity in the sands, and, other things being equal, the oldest sands should become the tightest. As a matter of fact, the older sands are often more porous than the younger ones. The Carboniferous sands are somewhat spotted in regard to their pore space, the porosity changing markedly from one outcrop to another. These sands, however, are not to be regarded as too tight for easy oil and gas movement.

Source rocks.—The so-called Chattanooga shale of northern Arkansas is petroliferous, and in places, at least, it will yield considerable oil on distillation. The small gas well northwest of Fayetteville evidently produces from the Sylamore

gas which has migrated there from the Chattanooga. Below this horizon, although sands are not rare, shales are uncommon and organic remains, as a rule, are wanting. Thus, though possible reservoirs are not lacking, source rocks are probably unimportant, in spite of the several shows previously pointed out.

The Fayetteville is a more important source rock than the Chattanooga, for it is nearly, if not quite, as petroliferous, and it is thicker and more widespread. There are oil seeps in the Wedington sandstone member of this formation; and *septaria* in the shale itself in some places carry enough oil to be ignited. Carbonaceous shales in the Morrow series and variegated shales of the Winslow formation are also petroliferous, but probably to a lesser degree.

The very fossiliferous limestones of the Chester group and Morrow series usually give off a strong odor of petroleum, and some contain cavities partially filled with liquid or solid hydrocarbons. Whether this oil was derived from the organic remains which crowd the rock, or whether it migrated there is not certain, but the fact that many of the cavities are the interiors of brachiopod shells may be construed as evidence for the former view.

The degree of metamorphism as shown by carbon ratios and its bearing on oil and gas possibilities.—In 1915 David White[1] advanced the theory that the percentage of fixed carbon in pure coal is an accurate index of the degree of metamorphism of the rocks containing the coal, and that, consequently, the general prospects for oil in areas where coals occur may be determined by a study of the carbon ratios of those coals. By studying the location of Appalachian oil pools with reference to the carbon ratios of coals of the same area, White was able to reach the conclusion that oil in commercial quantities was not to be expected where carbon ratios were higher than 65. The data presented by other oil pools and coals of North America, as well as of other continents, in the main justified his conclusion, and led him to add that the degree of regional metamorphism also determined the character of the oils in the area considered.

Although the latter idea has been questioned by McCoy,[2] the value and validity of carbon ratios have become fairly well established in the last decade. The number of geologists making practical application of White's principle, however, apparently is small, although several large companies have used it with considerable success. As a matter of fact, probably no scientific generalization of such profound economic importance has received less attention. The literature on the subject is scanty.

White[3] himself later discussed the problem in several additional papers;

[1] David White, "Some Relations in Origin between Coal and Petroleum," *Washington Acad. Sci. Jour.*, Vol. 5 (1915), pp. 189–212.

[2] A. W. McCoy, "A Short Sketch of the Paleo-Geography and Historical Geology of the Mid-Continent Oil District and Its Importance to Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5 (1921), No. 5, p. 570.

[3] David White, "Late Theories Regarding the Origin of Oil," *Bull. Geol. Soc. Amer.*, Vol. 28 (1917), pp. 727–34, and "Genetic Problems Affecting Search for New Oil Regions," *Trans. Amer. Inst. Min. and Met. Eng.*, Vol. LXV (1921), pp. 176–98, etc.

Fuller[1] has studied the carbon ratios of the Appalachian district and of the Pennsylvanian areas of north-central Texas and eastern Oklahoma; Reger[2] has shown the relationship of fixed carbon percentage and oil production for West Virginia; Semmes[3] has considered the significance of carbon ratios in northern Alabama; and Eby[4] sees in the high degree of metamorphism of the coals of southwestern Virginia the failure of oil prospecting there. Recently, Moulton,[5] in discussing the fixed carbon content of Illinois coals, pointed out the possibility of using the ratios to locate areas of greater deformation favorable to oil accumulation in regions of slight folding. So far as the writer is aware this completes the published papers strictly on carbon ratios, though, naturally, the subject has been mentioned casually in several articles on petroleum, and has merited a paragraph in several of the later textbooks. No doubt ultimately much more will be done with White's principle. Even without the refinements and qualifications which further study will evolve, it has been useful in pointing out areas in which pronounced metamorphism has made drilling risks prohibitively high.

A line drawn on a map passing through all points having the same fixed carbon ratio was originally designated by White as an isovol. This term he used as being less cumbersome than the "isoanthracitic lines" of Strahn and Pollard.[6] Isovol was changed to isovolve in Fuller's papers, but this appears to have been an unintentional corruption. White later suggested that the term isocarb was more accurate than isovol as originally used by him. Isocarb first appeared in print, however, in the paper by Semmes, though the term isovolve is used on the map illustrating his article. Reger, Eby, and Moulton use isocarb, and the term will be used in this paper. It is apparent that isovol, isovolve, and isoanthracitic line are synonyms of isocarb. Since they are somewhat less desirable than the latter term, they should be dropped from the literature in order to preserve uniformity.

Isocarbs in relation to oil-producing areas first appear on a map showing the regional alteration of coals and the location of oil fields in eastern United States, which is included in White's[7] original paper. In the Appalachian district, the eastern limit of the oil fields usually falls near isocarb 60, but small pools are found

[1] M. L. Fuller, "Appalachian Oil Fields," *Bull. Geol. Soc. Amer.*, Vol. 28 (1917), p. 649; "Relation of Oil to Carbon Ratios of Pennsylvanian Coals in North Texas," *Econ. Geol.*, Vol. 14 (1919), pp. 536–42; and "Carbon Ratios in Carboniferous Coals of Oklahoma and Their Relation to Petroleum," *Econ. Geol.*, Vol. 15 (1920), pp. 225–35.

[2] David B. Reger, "Carbon Ratios of Coals of West Virginia Oil Fields," *Trans. Amer. Inst. Min. and Met. Eng.*, Vol. LXV (1921), pp. 522–27.

[3] Douglas R. Semmes, "Oil Possibilities in Northern Alabama," *Trans. Amer. Inst. Min. and Met. Eng.*, Vol. LXV (1921), pp. 140–50.

[4] J. Brian Eby, "The Possibilities of Oil and Gas in Southwest Virginia as Inferred from Isocarbs," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 421–26.

[5] Gail F. Moulton, "Carbon Ratios and Petroleum in Illinois," *Ill. Geol. Survey*, Report of Investigations, No. 4.

[6] Strahn and Pollard, *The Coals of the South Wales Coal Field*, p. 72.

[7] *Op. cit.*, p. 199.

as far east as the 65 line. Gas fields fringe the oil fields on the east nearly to the 70 isocarb. The more detailed work of Reger[1] in West Virginia indicates that in this State many large oil pools occur above isocarb 55, some above 60, but none as high as 65, although some good wells have been brought in at or near the latter line. Gas is found between 65 and 70. Semmes[2] constructed an isocarb map of northern Alabama, and showed that what little oil and gas had been found came from areas lying between the 55 and 60 isocarbs. He considered areas where the carbon ratios ran higher than 65 as poor prospective oil territory. Moulton[3] has shown that in Illinois the areas disturbed by folding are regions showing increases in the carbon ratios of the coals. He points out, however, that due to the permis-

TABLE II

Sample No.	Location	Moisture	Vol. Mat.	Fix. Carb.	Ash	Carb. Ratio
1	Sec. 32, T. 16 N., R. 29 W.	.54	30.04	61.09	8.33	67.03
2	Sec. 21, T. 17 N., R. 29 W.	.61	26.89	61.57	10.93	69.60
3	Sec. 21, T. 17 N., R. 29 W.	3.35	29.14	61.24	6.27	67.75
4	Sec. 32, T. 16 N., R. 29 W.	.59	30.79	61.92	6.70	66.80
5	Sec. 10, T. 16 N., R. 30 W.	.20	25.91	55.73	18.16	68.26
6	Sec. 32, T. 16 N., R. 29 W.	7.40	25.98	58.30	8.32	69.17
9	Sec. 10, T. 16 N., R. 30 W.	1.20	27.18	66.50	5.12	70.98
10	Sec. 25, T. 14 N., R. 31 W.	4.79	22.96	66.35	5.90	74.29
11	Sec. 22, T. 13 N., R. 31 W.	.35	18.17	69.13	12.35	79.2
12	Sec. 32, T. 15 N., R. 29 W.	3.07	24.15	65.72	7.06	73.13
13	Sec. 1, T. 13 N., R. 32 W.	1.80	23.25	61.82	13.13	72.67
14	Sec. 1, T. 13 N., R. 32 W.	6.44	23.58	58.51	11.47	71.27
15	Sec. 19, T. 14 N., R. 31 W.	.59	26.91	61.58	10.92	69.59
16	Sec. 21, T. 10 N., R. 29 W.	1.60	20.25	75.39	2.76	78.82
17	Sec. 28, T. 17 N., R. 22 W.	.96	30.20	58.98	9.86	66.14

sible errors in the analyses, the carbon ratios of impure coals are subject to great variations.

In order to determine the carbon ratios for northwest Arkansas, H. L. Anderson[4] and the writer collected a number of samples of early Pennsylvanian coals from the Morrow and Winslow formations of that area. Unfortunately the coals are very thin, and, except where they have been mined for local consumption, are extremely hard to find. For this reason the samples are not as plentiful, nor do they represent as wide an area, as might be desired. No coal, for example, could be located east of Compton; and samples were not procured in the critical area of the Oklahoma Ozarks, though coals of sporadic occurrence are known there.

The samples obtained were submitted to the Pittsburg Testing Laboratories of Pittsburg, Pennsylvania, where proximate analyses were run, determining only moisture, volatile matter, fixed carbon, and ash. The results obtained are given in Table II.

[1] *Op. cit.*, p. 523. [2] *Op. cit.*, p. 141.

[3] *Op. cit.*, p. 11.

[4] To whom the writer is greatly indebted for valuable field assistance.

The samples numbered 16 and 17 came from the lower part of the Winslow formation; the others are from the coal which occurs in the shale between the Brentwood and Kessler limestone lentils of the Morrow group.

From these analyses and those made by the U. S. Bureau of Mines[1], as well as those given by the Missouri Bureau of Geology and Mines,[2] an isocarb map of the Ozark province and adjacent areas was drawn (Fig. 2). This map is admittedly generalized, and cannot but be wrong in some of its details. Additional analyses from the Boston Mountains, particularly near their western extremity, are needed to place correctly the important isocarb 65. Samples of the coals which occur in the Prairie Plains of both Oklahoma and Missouri just above the Mississippian-Pennsylvanian contact would aid greatly in reducing the uncertainty of the map in these areas.

In spite of these facts, however, the new analyses have so altered the isocarb map of Oklahoma as drawn by Fuller, and the general carbon-ratio map of the Interior Coal Fields by White, that it has seemed worth while to devote some space to a discussion of the new map and its significance. This is particularly true because the presence or absence of oil and gas in the adjacent parts of Oklahoma and Arkansas is of great importance in predicting their presence or absence in the area under discussion.

The isocarb 55 appears in Oklahoma essentially as Fuller has drawn it. Entering Kansas, it swings a little east of north until it passes into Missouri a few miles north of Fort Scott; thence it turns northeastward and finally crosses Missouri River northeast of Sedalia. Isocarb 60 is practically parallel to the 55 line north of Canadian River in Oklahoma, and both of these lines roughly tend to parallel the Prairie Plains–Ozark physiographic boundary. On Fuller's map the isocarb 60 is swung far to the east in the Muskogee area. In regard to this point Fuller says:

> There was little in advance of drilling to lead one to expect an area of low ratios back through Muskogee County to a point many miles east of the higher ratios to the north and south, but the occurrence and character of the oil seem to point rather conclusively to low carbonization. In the absence of coal analyses, the known general relationship between oil and carbon ratios has been used in drawing the isovolves.[3]

The analyses of the northern Arkansas coals seem to indicate almost, if not quite, conclusively that there is no reason for drawing this re-entrant. As a matter of fact even the character of the oils (42° Baumé) in the Muskogee area indicates a high rather than a low degree of metamorphism. But with this exception, the course of the isocarb 60 is as drawn by Fuller. The carbon ratios of Arkansas indicate that isocarbs 65 to 80, inclusive, cannot be as Fuller has shown them for Oklahoma. Hence, since Fuller was influenced in locating these lines by the structural relations, it is evident that structural conditions do not *necessarily* indicate the course of the isocarbs.

[1] *U. S. Bureau of Mines*, Bulletins No. 22, 85, 123, and 193.

[2] *Missouri Bureau of Geol. and Mines*, Vol. 11, 2d ser., pp. 428–35.

[3] *Op. cit.*, p. 233.

Isocarb 65 is located with certainty south of the Arkansas River Valley in Oklahoma, and again in northern Arkansas. It has been swung to the west of Muskogee

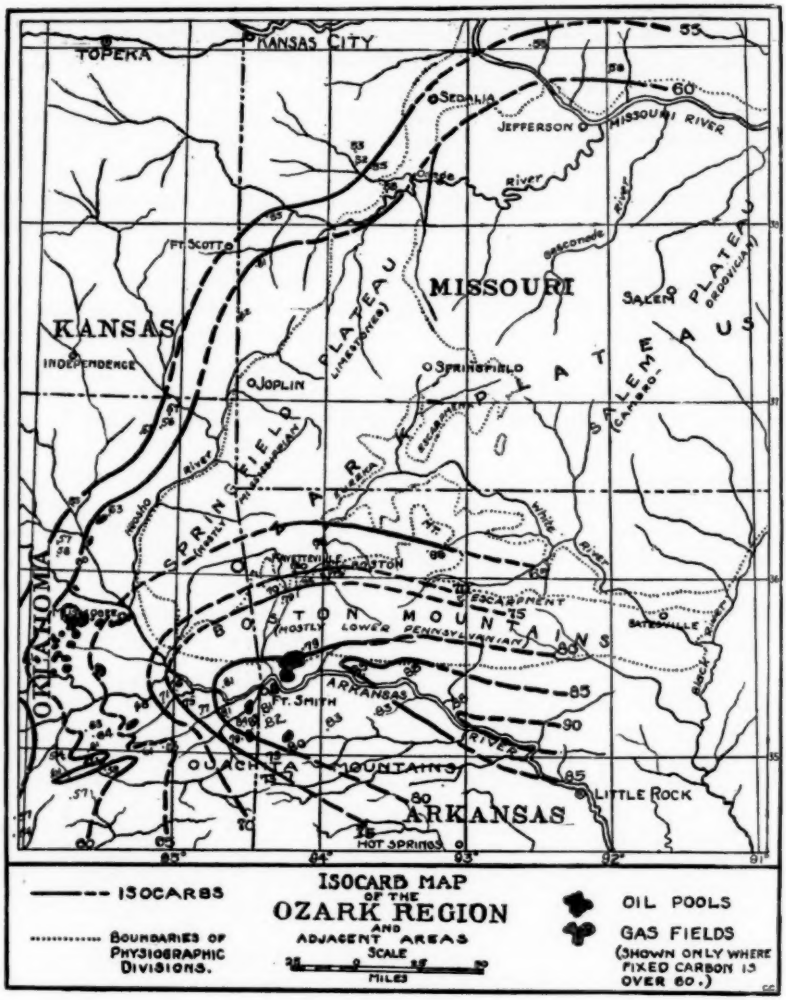

FIG. 2

in order that it might conform to the general trend of the higher isocarbs. Isocarb 70 is roughly parallel to the Boston Mountain escarpment, where its position has been determined by a number of analyses. It is again definitely located in the

Arkansas Valley. The 75 line is close to the 70 isocarb and in general conforms to its shape. Isocarb 80 is located accurately in the west, but analyses are lacking in the east. A number of analyses definitely locate isocarb 85, but again ratios are missing in the east. Isocarb 90 has been indicated provisionally, although no ratios higher than 88 have been recorded for Arkansas.

A study of the map indicates, if differences in the carbon ratios do accurately register different degrees of regional metamorphism, that the Ozark region suffered a thrust from the south, that the most intense metamorphism was localized in the moderately folded Paleozoics of the Arkansas Valley, and was less severe, though marked, in the intensely folded Ouachitas to the south. The map also shows that a little oil and considerable gas have been found above isocarb 65, that, indeed, the largest gas fields of the area considered lie above isocarb 80. It is apparent, then, that *so far as carbon ratios only are concerned*, no part of the Arkansas Ozarks is to be regarded as incapable of producing gas, and that oil of high grade in small, though commercial, quantities is not out of the question north of latitude 36.

Furthermore, the coal analyses on which the map was based make it clear that more study on the subject of carbon ratios is greatly to be desired. It seems apparent that the ratios do increase with depth, that unconformities account for sudden jumps in their value, that ratios are less in highly folded regions and along faults than in areas which have resisted the pressure applied without much folding or faulting, and that they are higher on anticlines than in synclines. But in spite of the fact that these generalizations are fairly well established, little work has been done with them in a quantitative way. Fuller and Moulton have pioneered in this study with some satisfactory results for limited areas. It will probably be very difficult to arrive at quantitative figures which will have universal application. If, however, these ratios were better understood, they would become of great importance in the study of major mountain structures where coal beds are present.

It might not be unreasonable to suppose that the thinner the coal the higher the carbon ratio, but so far as the writer is aware no studies have been carried out along this line. An examination of the analyses of coals of Arkansas failed to reveal any positive evidence in regard to this possibility. If there is a factor to be taken into consideration here, the ratios for northern Arkansas may be slightly high, since the coals are for the most part less than one foot in thickness.

Again, it must be remembered that it is surface ratios which are used as a basis for oil predictions, hence the isocarbs drawn on a producing horizon 2,500 feet deep might well be five degrees higher than those at the casing head. For this reason it is quite as reasonable to expect oil in a shallow well (1,250 feet), where the surface isocarb is 65, as in a deep well (5,000 feet), where the surface ratio is under 60. South of the Eureka escarpment in the Arkansas Ozarks one to three potential oil and gas sands may be reached everywhere by a shallow well.

From the tenor of the above discussion it should not be gathered that the writer questions at all the value of carbon ratios in ruling out areas unfavorable for the production of oil. He does feel that with the increasing search for new areas of

production, the knowledge of the relationship of carbon ratios to petroleum and gas is not now far enough advanced to warrant strong companies in condemning areas where the isocarbs are somewhat over 60, provided other conditions are favorable. Contrary to the general opinion, oil is by no means a rarity between 60 and 65, and gas in large quantities is common over 65. The important Poteau–Fort Smith-Alma gas fields of the Arkansas Valley, which are responsible for the industrial development of Fort Smith, certainly never would have been brought in had the operators been guided by the abnormally high carbon ratios in this district. As a matter of fact, geologists have been too prone to draw isocarbs on the basis of the presence and grade of oil rather than on the analyses of coals. This has been true in the case of the Muskogee district, as mentioned before, and the Healdton fields south of the Arbuckles, as well as in other instances.

CONCLUSIONS

From the previous discussion a number of facts become apparent. Those which appear to nullify the possibility of oil and gas production in the Arkansas Ozarks are:

1. The carbon ratios are higher than in the ordinary producing fields.
2. Considerable previous prospecting has not resulted in any commercial development.
3. Source rocks are not important in the Ordovician, which is the age of the surface rocks of the Salem Plateau.
4. The Boone limestone, which outcrops over much of the Springfield Plateau, is permeable, hence any hydrocarbons from the Chattanooga in this area are likely to have escaped.
5. Some of the sands are relatively low in pore space and others are spotted in regard to their porosity.
6. The sands containing oil generally are not saturated, at least at their outcrop.
7. Transportation facilities are poor.
8. There is no important market for gas, even if it should be obtained.

Those which should encourage prospecting are as follows:

1. There are gas fields in the adjacent Arkansas Valley where the carbon ratios are even higher than in northern Arkansas.
2. Most of the prospecting in the area has been done without regard to structure, so that the tests have not been conclusive.
3. Adequate source rocks are present above the Ordovician.
4. Gas shows are present in many wells; there is small gas production from a few.
5. There are many potential reservoir rocks, and at different horizons.
6. There are oil shows at several horizons, and some oil seeps.
7. Roads of good grade are being constructed to all parts of the region.
8. There has been a rapid growth of cities on the Springfield Plateau. If they could be supplied with gas they would probably become a fairly important market for the fuel.

9. There are several favorable structures.

10. Some oil occurs in the adjacent parts of Oklahoma, where the carbon ratios apparently are as high as in parts of the Arkansas Ozarks.

By weighing the favorable and unfavorable points against each other it is possible to reach the following conclusions: The carbon ratios in the Arkansas Ozarks indicate that, other things being equal, chances for oil increase from the south to the north. Erosion, however, has removed the most promising source rocks from the northern part of the area, and therefore oil in commercial quantities should not be hoped for there. The Springfield Plateau also has suffered so much erosion that only the Chattanooga remains as a source rock; and the Boone is not an adequate covering for this formation. Nevertheless, under favorable structural conditions, small amounts of oil and gas may be obtained in this area from the Sylamore sandstone. The Carrollton dome should be tested to this horizon at least.[1] There is a fairly good chance for gas in the Boston Mountains, and small pools of high-grade oil are possible. No oil is likely to be found near the Arkansas Valley, and the high carbon ratios make large pools practically impossible anywhere in the area. That these high ratios are not prohibitive of important dry gas fields is indicated by the fields which occur in the Arkansas Valley, where the degree of metamorphism is even higher.

[1] Since this paper was submitted, the writer has received notice of a well drilled on the Carrolton dome, which had a reported initial production of 1,000,000 cu. ft. of wet gas from the Sylamore sandstone. The report was probably exaggerated for the well was soon abandoned, but there is evidence that considerable gas was obtained. The sand, which was less than two feet thick, was reached at about 400 feet.

PREVENTIVE MEDICINE AND HEALTH IN VENEZUELAN OIL FIELDS[1]

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ABSTRACT

Extreme tropical conditions characterize the Maracaibo Basin, but the entrance of large oil companies into the area has dispelled many erroneous ideas about the terrors of the jungles. No one need hesitate about going to Venezuela if he possesses ordinary health. None of the deadly plagues exists there. Malaria is common, but readily controlled by protection against mosquitoes and by the proper use of quinine. Although the jungle is inhospitable and is inhabited by tigers and snakes, the insects are the most dangerous, and these can be successfully combated. Temperance and morality are necessities to health in the tropic. Anyone leading a clean life and observing a few simple rules of prophylactic medicine will find the tropic wholesome.

INTRODUCTION

It is surprising to how many otherwise well-informed persons the word "tropic" conjures up visions of flaming heat, impenetrable jungle overrun with man-hunting beasts, and deadly vermin of fantastic shapes, while the virus of mysterious and fatal diseases floats in the telluric miasma which saturates the very air breathed; to them, death stalks at every turn in the tropics, and the grave is just one step ahead.

The invasion of South American fields by the great oil companies of America, and their success there, has already accomplished much toward dispelling these fanciful conceptions born of ignorance fostered by the imaginative writers of tropical lore and sensational melodramatic travel books, who perhaps have never themselves crossed the tropic of Cancer. As many geologists may not be fully acquainted with actual conditions in the new and rich petroleum fields of Venezuela, it will not be amiss to give a true sketch of health problems, from the standpoint of preventive medicine, as I see them after close study and observation throughout many years.

CLIMATE

Extreme tropical conditions prevail in the Lake Maracaibo basin, but although the temperature is warm throughout the year, with a cooler season lasting from December to February, it never reaches as high a level as it does every summer in the United States. The average high temperature in the Maracaibo district, which has the reputation of being the hottest zone in Venezuela, is 95° F., the average minimum is 68°, and the average mean temperature is 82.5°. The average mean humidity is high, more than 97 per cent, and the average yearly rainfall low,

[1] Read before the Association at the New York meeting, November 15, 1926.

[2] Medical director, Venezuela Sun Company Ltd. Introduced by Fred H. Kay.

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23.5 inches. The heat is tempered by the constant play of the trade winds, and the sun rays are devoid of the deadly properties they possess in India and Africa; a helmet never need be worn, for you can walk in the sun all day with a straw or Panama hat on, without danger; cases of true insolation in Venezuela must be very rare, for I have never observed a single case.

The clothing should be of the coolest fabrics: Shantung silk, Palm Beach, white duck and cotton drills are the appropriate materials.

Americans and Europeans, men, women and children, stand the climate of the region remarkably well, and though it is not invigorating, like that of the temperate zone, it certainly is not injurious. Under its influence there is merely a diminution of the superabundance of energy observed here, but this does not mean any real impairment of the vital forces; a desire to take life a little easier creeps over you, and you begin to think that there is no sense in rushing too much, for life is long and sweet and there are many days ahead; the task can certainly wait to be finished *mañana*.

A man whose health is undermined by any organic disease, or is far below par physically from recent acute illness, should avoid the tropics until full recovery. But no one who enjoys ordinary health need feel any hesitancy about going to Venezuela; if he lead a clean life and follow a few simple and obvious prophylactic rules, he will enjoy just as good, and probably better, health down there than ever before. None of the great and deadly plagues of other tropical zones, such as bubonic plague, cholera, yellow fever, or typhus, exists in Venezuela.

MALARIA

There is no autochthonous malaria in the city of Maracaibo, headquarters of all the oil companies, but it is a different story elsewhere. If malaria could be eliminated as a nosologic factor in the oil fields, they could easily be rendered as healthful as any health resort in this country, for malaria is responsible for more disability than almost all the other diseases combined. Unfortunately, an attempt to banish malaria from the Lake Maracaibo basin would be a task of far greater magnitude than even the sanitary conquest of Panama, and would involve the expenditure of untold millions. Since this is out of the question, in our fight against malaria we must confine ourselves to local measures, and a great deal can be accomplished thereby.

To fight the mosquitoes with all available weapons is to wage an effective war against malaria. Clearing the ground in a width of 200 yards around field camps, screening all houses, and using mosquito nets over the beds as an additional protection where the insects are plentiful, are imperative measures.

Drainage of the land is the most important step in the control of malaria, seconded by oiling of all collections of water which cannot be eradicated, and supplemented perhaps by the use of a larvicide.

The daily administration of quinine as a prophylactic has been criticized by men working in zones where malarial infection is less intense than it is in the lower

Maracaibo fields, but I have proved to my own satisfaction that it is a method of immense value, and the only way of keeping up the efficiency of the field organization. With only occasional exceptions, ten grains of quinine daily given to a native laborer will keep him working indefinitely, even in the worst malarial districts. We advocate fifteen grains for our American employees. This does not mean that these men are cured of their chronic malaria, or that they cease to harbor in their blood the gametes, or latent germs, of malaria, but that amount of quinine is sufficient in most cases to prevent any paroxysms of fever. The eventual elimination of the gametes from the blood depends on the individual's own powers of resistance against the malarial organism. The occasional attacks of fever that some of these men may have are always mild, and I have never witnessed a malignant or fatal attack in persons taking daily prophylactic doses of quinine.

No fresh case of malaria which is promptly treated with appropriate doses of quinine is ever dangerous; the dangerous case is the one where recurring paroxysms have been neglected or ignored, as in such instances a malignant attack may unexpectedly come on at any moment and promptly end fatally.

I have often been asked if the prolonged use of even the small doses of quinine advocated as a prophylactic is not injurious, and whether malaria does not leave in the system some permanent damage. I can answer both questions emphatically in the negative; such, at least, is my opinion.

INTESTINAL PARASITES AND WATER-BORNE DISEASES

Intestinal parasitism is very common in the tropics among the natives on account of their poverty and careless habits, but rare among white foreigners. These parasites gain entrance to the body either through the epidermis, as in walking barefooted in contaminated soil or water, or their eggs or larvae are ingested in contaminated food, water, or milk. Flies are justly suspected of spreading these diseases, and the mouths of pet animals may harbor their germs.

Milk and water should be boiled; lettuce and other salad vegetables should be soaked in chlorinated water, food should be protected against flies. Do not let pet dogs and cats kiss you, and never walk barefooted on the ground or wade in stagnant water. By observing these rules, you not only avoid the possibility of infestation with intestinal parasites, but you also protect yourselves against the most serious diseases prevailing in the tropics, the dysenteries, and the group of the typhoid, paratyphoid, and bacillus coli infections.

In the staff houses and camps, boiled or distilled water exclusively should be supplied, and for field use Halazone tablets are convenient to carry; one tablet dissolved in one quart of water, which is the usual capacity of a canteen, will render the water safe to drink within a half hour.

I advocate the use of prophylactic bilivaccines as a precautionary measure against bacillary dysentery and typhoid fever. The simplicity of their administration, by mouth, and their seeming efficiency in protecting against these diseases justify their more extended use.

THE DESERT AND THE JUNGLE

Nearly all the oil territory in Venezuela under production, and most of the prospective fields, are located in a strip of lowland surrounding Lake Maracaibo. This land, to the north, including the state of Falcon to the northeast, is a semi-arid sandy plain resembling somewhat the desert country of Arizona, with very sparse vegetation consisting mainly of cacti and acacias, upon which the numerous goats scattered in this region feed. Numberless parrots and paroquets and brilliantly plumaged birds inhabit this desert. The people live in shacks entirely built of mud, including the roof. They subsist on heaven knows what, and depend for a water supply on the rain water, which they succeed in collecting on the surface of the ground by building a mud dam around a likely despression. These remarks about the scarcity of water have reference only to the desert country of Falcon, where a new and promising oil field has just been proved. Fields along the lake shore are ideally situated. To the south, the whole territory from the lake to the foothills of the Andes is a vast jungle. It begins as a narrow strip hugging the lake shore, but widens as it approaches the equator, to reach a maximum width of more than 100 miles southwest of Lake Maracaibo. This jungle is traversed by innumerable rivers, small streams and swamps, and is thickly populated with myriads of insects of all imaginable varieties, which give the impression of being the real owners of the land. The surface of the ground is studded with the quaint conical houses of termites, and scarred with the burrows of the leaf-cutting, fungus-growing attine ants. These countless holes fill up with water during the rainy season, and afterward retain the stagnant fluid for long periods, to serve as ideal breeding places for anopheline mosquitoes.

The jungle affords a vision of sheer wilderness, but not of majesty: you must go farther inland, to the foothills of the great Andean range, to admire the incomparable beauty and grandeur of the primeval tropical forest in all its glory. The jungle, insect-infested, thorny, tangled, and almost impenetrable like a closely woven wall of verdure, offers as inhospitable a panorama as could possibly be imagined, and seems like a land of silence and death. But this is mainly a psychologic reaction; as a matter of fact you are quite safe in the jungle. The only dangerous enemies to beware of are poisonous snakes, particularly the species called by the natives *macagua*, better known elsewhere as "fer-de-lance." Its scientific name is *Bothrops atrox*, a snake closely allied to the North American species *Lachesis muta* or bush master. If untreated, its bite is often fatal or mutilating. Fortunately, ophidic accidents are rare even here; out of a large force of American employees and native laborers operated by the Venezuelan Sun Company no white men and only two native peons have been bitten in the last six years. Poisonous snakes are extremely rare in the northern desert country, where all the present producing fields are located.

All engineers and geologists detailed to work in the field, especially in the jungle, should carry with them a snake-bite outfit for the local treatment of snake bites. By far the most effective measure is the injection of the polyvalent anti-ophidic serum, first produced in Brazil and soon to be available in this country. It

gives brilliant results, curing practically every case if used reasonably soon after the accident. A supply of this serum should always be kept on hand in the field camps, and men working in the jungle should carry an *ampoule* with them.

Tigers are plentiful in the jungle, and their imposingly large footprints are to be seen everywhere, but I have never known of an authentic report of one attacking a man in Venezuela. You rarely meet them face to face, and when you do, the surprise and fright of the encounter seems to be reciprocal.

Of the poisonous arthropods three families deserve mention because of their wide distribution and ill reputation. Not one of them is really dangerous to life, and their ability to inflict a very painful, poisonous sting or bite is largely neutralized by their sluggishness and timidity. When discovered, all their efforts are concentrated on a quick get-away, and they never attack you unless you accidentally touch them. They are the giant hairy spiders of the superfamily *Avicularoidea*, improperly called tarantulas, the scorpions, and the centipedes, particularly the giant centipede, *Scolopendra gigantea*.

So far I have enumerated comparatively large enemies, things with a body and substance that you can see and defend yourself against; the struggle is decidedly one-sided and you always win. But the problem becomes very much more complex when you have to fight shadows, the invisible little beings scarcely bigger than a speck, which launch their unsuspected attacks in the dark, usually during your sleep, and are capable at times of inoculating you with a variety of diseases, such as malaria, dengue, filariasis, *gusano* or mosquito-worm, relapsing fever, papatasii fever, Chagas' disease, and perhaps Oriental sore and tropical ulcer. These enemies include mosquitoes, sand-flies, reduvids or bugs resembling those found on the stalks of tender green plants, and bed-ticks.

I have already discussed the general methods of combating mosquitoes. *Phlebotomos papatasii*, a sand-fly, and the *Simulidae*, or gnats, are incredibly annoying pests; happily they are found in large numbers in but few localities. They are so small that they pass readily through the meshes of both screen and mosquito net, and they must be fought off by the burning of pyrethrum, or a smudge, or by the local application of a repellent such as tar oil, or the essential oil of citronella, or a mixture of kerosene and oil of pennyroyal. Incidentally, these simple methods will also keep away mosquitoes and most other insects. The natives avoid them by shutting themselves up at night in their habitations, excluding all light and incidentally all ventilation. Mosquitoes, sand-flies, and gnats do not fly in utter darkness.

Two blood-sucking bugs, *Rhodnius prolixus* and *Ornithodoros venezuelensis*, roam the natives' palm-roofed shacks at night for food. They are capable of transmitting disease, and it is the part of wisdom to shun the hospitality of the native's hut at night unless you have with you a mosquito net.

If you put your high boots on before you step on the bare ground when camping in the field, you will not be called upon to supply the flesh of your toes for shelter, incubating space, and banquet meat to the infinitesimally small chigger *Dermatophilus penetrans*.

Dermatobia cyaniventris is an interesting jungle fly. We are especially concerned with its life-history because in its larval stage it is a parasite of man as well as of animals. In the woods, this fly deposits its eggs in packets covered with a very viscid substance, on top of certain green leaves which are especially attractive as resting-places to mosquitoes of the species *Janthinosoma lutzi*. The packets of eggs become accidentally attached to the abdomens of these mosquitoes, and the embryos are soon hatched and develop in their aeroplane-like home. At the top of the egg shell there is an operculum or window-like opening that the little worm can open or close at will, and through which he will emerge upon smelling blood, when the mosquito that bears him lights for a feed on an unsuspecting petroleum geologist. Once the worm drops on the skin, it immediately burrows its way into it, and settles down to enjoy for awhile a carefree existence, our flesh supplying both shelter and food. It grows rapidly, and eventually develops into a disgusting, hairy maggot, half an inch long, giving rise to a painful boil with a small opening at its apex through which the worm breathes. If you try to fish it out it plays hide and seek by promptly disappearing from view into the depths of its fleshy home. If not removed surgically it eventually drops to the ground, to complete there its life-cycle.

TEMPERANCE AND MORALITY

In the tropics the great detoxicating organ, the liver, does not seem able to withstand the gross insult of large doses of strong alcoholic drinks as well as it does in cold climates. It is no idle admonition to recommend moderation in the use of liquor with more emphasis than might seem necessary in the temperate zone.

Venereal diseases, every known variety, are rife in all parts of the tropic, and no man can lead with impunity an existence of pleasure and indulgence. He is certain to pay dearly for it in health, a price much too high.

In conclusion, the tropic is not bad. We have to contend with a few diseases which are rare or unknown in the United States, but we are not plagued with others which exact every year a heavy toll in this country. The ills that man falls a prey to down there are mostly the result of ignorance, of carelessness or indifference, or are the penalty for transgressions. If you lead a clean life and observe a few simple rules of prophylactic medicine, you will find the tropic wholesome. The barriers which to some extent regulate people's conduct in the United States and keep them, often against their will, from indulging too freely in noxious pleasures do not exist in South America, where man is curbed only by his own moral sense; if the blind animal instinct in him to indulge in everything he craves is stronger than his judgment, he must yield in tissue resistance to disease the price of his intemperance; but then, he is only reaping what he sowed.

When you leave the shores of this, the greatest of all countries, to settle beyond Cancer, you give up a great deal indeed; but on the other hand, life over there also has its compensations; it flows more gently and serenely, in a quieter sphere, and once you have learned to love its beautiful sky, the mystery and charm of the tropic under the Southern Cross will call you back to its shores as long as you live.

GEOLOGICAL NOTES

GEOGRAPHIC DISTRIBUTION OF GEOLOGISTS IN THE UNITED STATES

On the accompanying map is recorded, as fully as available data will permit, the geographic distribution by states of geologists in the United States. The list of geologists from which the map is made has been compiled from various sources: first, from the membership of four national geologic societies; later, after some additions from various sources, the list was submitted to at least one organization in

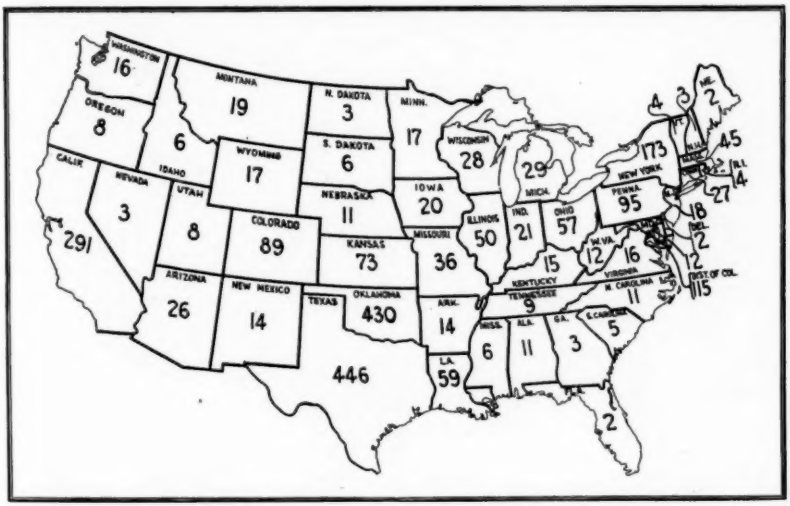

FIG. 1.—Geographic distribution of geologists in the United States

each state, usually the state geological survey. The writer is indebted to these organizations for correcting and supplementing the list. Although obviously incomplete, the data are believed to be comprehensive enough to serve a useful purpose.

The geologists included in this list are those who have had training in geology equivalent to that obtained in the courses required in a college or university of recognized standing in which geology is selected as the major subject, and who in addition have continued in geologic work for a minimum of three years following graduation. The list is intended to apply to the group of geologic sciences in a broad sense including geology, paleontology, mineralogy, petrography, engineer-

ing geology, and physiography. Thus defined, the number of geologists in the United States at the present time is found to be about 2,387.

The seismograph and torsion balance investigations in geology are being conducted at present in part by geologists, but more largely by physicists. Of this group, including at present possibly fifty scientists in the United States, the geologists only are included in this count. The physicists in this work, however, no less than the geologists, are contributing to the advance of the geologic sciences.

E. H. SELLARDS

UNIVERSITY OF TEXAS
January 31, 1927

DISCUSSION

GEOGRAPHIC NAMES OF THE EASTERN COAST OF RUSSIAN SAKHALIN

In the November number of the *Bulletin* appeared an important "Preliminary Report on the Geology of the Oil Fields in North (Russian) Sakhalin," by Giichiro Kobayashi, chief geologist of the Japanese Geological Survey, and one of the most prominent oil geologists of Japan. The article is of special interest, since it is the first authoritative

Names as they appear in Dr. Kobayashi's article	As they should be written
Ehabi	Ekhabi
Oha	Okha
Niuvo	Nyivo
Kiacle	Kyakr
Napirisky	Nabil or Nabilski
Nuisky	Nyisky
Shumit Peninsula	Schmidt
R. Tuimi	R. Tym
Adatuimi	Ada-Tym
C. Delir de la Croail	C. Delisle de la Croyere
R. Waar	R. Val
R. Gigian	R. Jimdan or Gimdan
R. Pilitoone	R. Piltun
Katanguri	Katangli
Paromai-Quidrany	Paromai-Kydylani
Wenie	Uini
Congie	Kongi
Azap	Odoptu?
R. Kioniga	R. Koenig
Handooza	Handuza
Nogrik	Noglik
Wegrek	Uiglekut
Chakkalesky	Chakri

geological report written in English of the explorations by the Japanese geologists during the military occupation of the island, when Japan was practically its sole possessor and rather jealously guarded the oil-bearing region and all information concerning it.

Being a chemist, I write not to criticize the essential substance of the report, but merely to correct the terminology used in it. Apparently, the author used only Japanese maps written in "katakana," without consulting the original Russian or English maps or considering the phonetics of the names. For the most part, the names of the eastern coast of Russian Sakhalin are the original names of the native inhabitants. Japanese "katakana" (the monosyllabic alphabet used by Japanese in the transliteration of the foreign

names and words) is not only inadequate for the complicated phonetics of the Sakhalin names, but often it renders them unrecognizable. Thus one of the largest lagoons, called "Kyakr," appears as "Kiacle"; lagoon Nabil, or Nabilski, figures as "Napirisky."

In the list (p. 307), I am placing in the first column geographic names as they appear in Dr. Kobayashi's article, and in the second column the names as they should be written.

It must be evident to the readers that the use of the names as given in Dr. Kobayashi's article will inevitably lead to great confusion.

TAISIA STADNICHENKO

NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C.
December 22, 1926

MOSS BLUFF SALT DOME DISCOVERY

In a recent note[1] in regard to the discovery of the Moss Bluff salt dome, credit for the discovery was given to "a seismograph leased from the Rycade Oil Corporation and operated by members of that organization." Credit for the discovery of the dome should be given to Geophone Troop No. 2, of the Geophysical Research Corporation. The Geophysical Research Corporation is operated separately from either the Rycade Oil Coropration or the Amerada Petroleum Corporation, and its personnel is independent from the personnel of either of those companies.

DONALD C. BARTON

HOUSTON, TEXAS
January 7, 1927

NOTES ON THE STRATIGRAPHY OF THE UPPER CRETACEOUS FORMATIONS OF TEXAS AND ARKANSAS

A CORRECTION

On page 12 of my paper entitled, "Notes on the Stratigraphy of the Upper Cretaceous Formations of Texas and Arkansas," published in the January, 1927, number of the *Bulletin*, I made the following statement:

"A chalk exposed in the vicinity of Okolona, Clark County, Arkansas, is correlated by Miss Ellisor with the Pecan Gap chalk, that is, upper Annona. This chalk contains a fauna of echinoids and mollusks that proves conclusively its Saratoga age."

The quoted statement refers to a paper by Miss Alva C. Ellisor, entitled, "The Age and Correlation of the Chalk at White Cliffs, Arkansas, with Notes on the Subsurface Correlations of Northeast Texas," published in the November, 1925, number of the *Bulletin*, in which on page 1158 she says:

"This same fossiliferous sand occurs north of Okolona, Arkansas, in Sec. 27, T. 8 S., R. 22 W., just below the Pecan Gap formation which is represented by a sandy chalk."

At the time my paper was prepared it was assumed that the sandy chalk to which reference is made in the preceding quotation, was the Saratoga chalk which outcrops in Okolona and at several localities within a few miles of that town. This assumption seemed justified because this chalk had been mapped by A. C. Veatch as Annona, and neither Mr. C. H. Dane, who was then engaged in a study of the Cretaceous formations of

[1] Wallace E. Pratt, "Two New Salt Domes in Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 11 (1926), p. 1171.

southwestern Arkansas, nor I, knew of any other chalk in that vicinity. However, in a letter dated January 29, 1927, Miss Ellisor states that she did not refer to the chalk mapped by Veatch, as I had supposed, but to a sandy chalk which she observed in a freshly dug grave north of Okolona, presumably in Sec. 27, T. 8. S, R. 22 W. This sandy chalk evidently occupies a lower stratigraphic position than the Saratoga chalk, and is probably included within the upper part of Dane's Ozan formation; as the Ozan corresponds in age to part of the Annona chalk at Clarksville, Texas, the sandy chalk might well carry a Pecan Gap micro-fauna.

I am glad to take this opportunity to correct my erroneous assumption.

L. W. STEPHENSON

U.S. GEOLOGICAL SURVEY
WASHINGTON, D.C.
February 2, 1927

REVIEWS AND NEW PUBLICATIONS

"Petroleum Geology in Oklahoma." By SIDNEY POWERS. *Oklahoma Geological Survey Bulletin No. 40–G.* Norman, Oklahoma, December, 1926. Pp. 24.

Dr. Powers may have overlooked a point or two in this comprehensive work, but the reviewer fails to find any important omission. The wonder is that a complete story of Oklahoma petroleum geology could have been condensed into the short space of twenty-four pages. As Dr. Gould states in his Foreword, the author is well qualified to write the chapter on the history of oil geology because of his wide acquaintance with working geologists and men engaged in petroleum research. But not only that, the bulletin is compiled in the thoroughly painstaking manner that characterizes all of Dr. Powers' scientific publications.

It is divided into two parts: first, "History"; second, "Relation of Geology to Oil Production."

The first part, "History."—Herein are taken up chronologically the individual geologists, beginning in 1903, briefly describing the professional life-story of each down to the present time. But, as explained, with the great influx of men in 1914 it became impracticable to name individuals further. Perhaps that is why Powers did not mention his own outstanding personality, the value of which is recognized by us all.

Histories are written in two ways: by reminiscences of what the author himself has passed through, or by testimony of witnesses contemporaneous with events. Perhaps for this reason, and because this reviewer is given the opening three paragraphs, reminiscences occur to him.

It might be added to the footnote concerning G. H. Eldridge's monograph on "Asphalt and Bituminous Rock Deposits" (*U. S. G. S. 22d Ann. Report*, 1901), that in describing the Wheeler, Indian Territory, seepage, Eldridge makes a significant remark, "The deposit is of interest in its bearing upon the presence of oil at depths, and is another evidence of the possibilities of the region, etc." The Wheeler geologist did not read this until later, as correctly stated in Dr. Powers' bulletin, but he was grateful that he ignorantly happened into such good scientific company in independently applying an idea. A visit from W. J. Reed in 1909 is recalled. He was at that time engaged in field work on the "Madill Oil Field" (*U. S. G. S. Bull. 381*, 1910).

There is another name that does not appear in *Bulletin 40–G*, that of a very well-known pioneer geologist—William Kennedy, who died in February of 1926. Kennedy was at that time (about 1907 or 1908) with the Rio Bravo Oil Company (Southern Pacific), and no doubt, at the time he visited the Wheeler producing wells, was engaged on one of the confidential (unpublished) reports which his biographer refers to in the memorial published in the *Bulletin of the American Association of Petroleum Geologists*, Vol. 10, No. 9 (September, 1926). Probably also he obtained then preliminary geological information that subsequently made him of value to the Lone Star Gas Company in southern Oklahoma. Whatever his duties, his visit at the Santa Fe Wheeler Oil Camp was appreciated, and his broad grasp of the Carter County geology, even at that early day, was helpfully instructive to the local geologist in charge of development.

Naturally, at the time of preparation of his material for *Bulletin 2, Oklahoma Geological Survey*, L. L. Hutchison was welcomed at the Wheeler field, and his call there was pleasing. Aside from these three men, if other geologists came to the first Carter County field, either they failed to make themselves known or are not remembered.

The second part, the "Relation of Geology to Oil Production."—Although the first part is valuable from a reminiscent viewpoint, and as reference to persons who were fortunate enough to be in Oklahoma and Indian Territory in the early days of geology, the second part is the really valuable part of the paper, for in it is taken up, all too briefly, every problem that has interested the petroleum geologists, first and last, in Oklahoma, since 1913. While personal mention is made in connection with individual contributions to science, it is to be remarked that without the footnote added by Dr. Gould on page 14, the lay reader would not have been led to give the credit due Mr. Powers for "the discovery of Ordovician fossils in a producing well shot in the oil sand at Healdton in November, 1916." Furthermore, the author refers casually to "buried hills," but does not write of his own contributions to that subject.

In the Summary of the *Bulletin*, the statement is made that "oil seepages had less to do with oil development than in almost any other part of the world." Apparently Powers here confuses past history with present problems and methods. It can easily be shown that in Carter and Stephens counties, and perhaps Marshall County, of Southern Oklahoma, the present production was directly or indirectly due to proper locations suggested by surface seepages or showings of oil or gas. In some other parts of Oklahoma, attempted development and sometimes later successes depended upon surface showings just as in other parts of the world. While the progress of geology, which he has described, has passed beyond that point, it would be well for the younger geologist to know that oil seepages have, in the past, had this bearing on the present situation. This might be thought a quibble, but it raises a point for thought.

There is also a question as to his definition of "strictly geological work." According to the constitution of the American Association of Petroleum Geologists, Article 2, and the reviewer's interpretation, the present-day petroleum geologist is more truly an engineer, and should have, in addition to geology, a working knowledge of petroleum technology, civil, mechanical, efficiency, and financial engineering. This idea seems to have been borne out by the scope of the papers appearing in the bulletins of the Association, covering all these branches. If this interpretation is not correct, then the men engaged in "strictly geological work," who would not be supposed to know how a well is drilled or produced or handled, will decrease. Possibly when production decreases, the number of workers in all lines will decrease; but if the geologist's field is as broad as here outlined, it appears that there should be no dread of the thoroughly equipped geologist working himself out of a job.

Bulletin No. 40-G is a publication that every geologist should have for historical reference, should consult frequently, until he knows every line, for it shows the wonderful progress of our most important science. Furthermore, arguing from the past and present, there is a hint that, notwithstanding the author's conservatism, the science has not yet attained the summit. There may always be some unsolved problem on which to work.

H. B. GOODRICH

TULSA, OKLAHOMA
January 19, 1927

RECENT PUBLICATIONS

ALABAMA

"Geology of Alabama," by George I. Adams, Charles Butts, L. W. Stephenson, and Wythe Cooke. Prepared in co-operation with the U. S. Geological Survey. Special Report 14, *Geological Survey of Alabama*, University, Alabama. Cloth, 312 pp. Price, $1.20.

COLORADO

An *Areal and Structural Geologic Map of Otero County, Colorado*, by Charles T. Lupton, is being distributed free by citizens of Otero County, Colorado. Lajunta is the county seat.

INDIANA

"Geological Conditions of the Oil Fields of Southwestern Indiana," by W. N. Logan. Publication 42, *Indiana Geological Survey.*

"Geology of Deep Wells of Indiana," by W. N. Logan. Publication 55, *Indiana Geological Survey.*

Both of these publications may be obtained for $1.50 by writing the State Survey, Indianapolis, Indiana.

KANSAS

"Geologic Investigations in Western Kansas, with Special Reference to Oil and Gas Possibilities. 1. Geology of Ellis County. 2. Geology of Hamilton County. 3. Geologic Structure of the Dakota Sandstone. 4. Structure and Limits of the Kansas Salt Beds," by N. W. Bass. Prepared in co-operation with the U. S. Geological Survey. Bulletin 11, *State Geological Survey of Kansas*, Lawrence, Kansas. Price $0.20.

OKLAHOMA

"An Engineering Report on the Davenport Oil Field, Lincoln County, Oklahoma," by R. R. Brandenthaler, K. C. Sclater, and H. M. Kent. *U. S. Bureau of Mines.*

TEXAS

"The Deep Boring at Spur," by J. A. Udden. Bulletin 363, *Bureau of Economic Geology, University of Texas*, Austin. A reprint. Price $0.75.

"Microscopic Characteristics of the Bend and Ellenburger Limestones," by J. A. Udden and V. V. Waite. Bulletin 2703, *Bureau of Economic Geology, University of Texas*, Austin. A reprint. Price $0.25.

"On Scott's New Correlation of the Texas Midway," by Julia Gardner. *American Journal of Science*, Vol. XII (November, 1926), pp. 453–55.

THE ASSOCIATION ROUND TABLE

THE CONSTITUTION OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

ARTICLE I. NAME

This Association shall be called the "American Association of Petroleum Geologists."

ARTICLE II. OBJECT

The object of this Association is to promote the science of geology, especially as it relates to petroleum and natural gas; to promote the technology of petroleum and natural gas and improvements in the methods of winning these materials from the earth; to foster the spirit of scientific research amongst its members; to disseminate facts relating to the geology and technology of petroleum and natural gas; to maintain a high standard of professional conduct on the part of its members; and to protect the public from the work of inadequately trained and unscrupulous men posing as petroleum geologists.

ARTICLE III. MEMBERS

SECTION 1. Any person actively engaged in the work of petroleum geology or in research pertaining to petroleum geology or technology is eligible to active membership in the American Association of Petroleum Geologists, provided he is a graduate of an institution of collegiate standing, in which institution he has done his major work in geology, and in addition has had the equivalent of three years' field experience in petroleum geology; and provided further that in case of an applicant for membership who has not had the required collegiate or university training, but whose standing in the profession is well recognized, he shall be admitted to membership when his application shall have been favorably and unanimously acted upon by the executive committee; and provided further that these requirements shall not be construed to exclude instructors and professors in recognized institutions of learning whose work is of such character as in the opinion of the executive committee shall qualify them for membership.

SEC. 2. Any person having completed as much as thirty hours of geology (an hour shall here be interpreted as meaning as much as sixteen recitation or lecture periods of one hour each, or the equivalent in laboratory) in a reputable institution of collegiate or university standing, or who has done field work equivalent to this, shall be eligible to associate membership in the American Association of Petroleum Geologists, provided that at the time of his application for membership he shall be engaged in geological studies in an institution of collegiate or university standing, or shall be engaged in geological work.

SEC. 3. Active and associate members shall be elected to the Association according to the qualifications outlined in Sections 1 and 2, provided that the applicant properly fills out the regular application blank, including the signatures of *three* active members of the Association, and that such application be approved by at least three of the members of the executive committee of the Association, as provided for in Article IV, Sections 1 and 4.

SEC. 4. Associate members shall enjoy all privileges of membership in the Association, save that they shall not hold office, sign applications for membership, or vote in

business meetings; neither shall they have the privilege of advertising their associate membership in the Association in professional cards, nor shall they have the privilege of signing professional reports as associate members of the Association.

SEC. 5. Each applicant for membership shall formally be notified in writing by the secretary of his election, and shall be furnished with a membership card for the current year; and until such formal notice and card are received, he shall in no way be considered a member of the Association.

SEC. 6. Applications for membership may be accepted at any time, but unless an applicant shall have his application approved and have been formally notified by the secretary of his election at least one month before the annual meeting, he shall not be allowed to participate in the business of said annual meeting.

SEC. 7. The executive committee may from time to time elect as honorary members persons who have contributed distinguished service to the cause of petroleum geology. Honorary members shall not be required to pay dues, nor shall they be allowed to vote.

ARTICLE IV. OFFICERS

SECTION 1. The officers of the Association shall consist of a president, a vice-president, a secretary-treasurer, and an editor-in-chief. These, together with the retiring president, shall constitute the executive committee of the Association.

SEC. 2. The officers shall be elected annually from the Association at large.

SEC. 3. No man shall hold the office of president or vice-president for more than two years in succession.

SEC. 4. The executive committee shall consider all nominations for membership and pass on the qualifications of the applicant; shall have the control of the Association's work and property; shall determine the manner of publication, and pass on all materials presented for publication; and may call special meetings when and where thought advisable, and arrange for the affairs of the same.

SEC. 5. The officers elect shall assume the duties of their respective offices one month after date of election.

ARTICLE V. MEETINGS

The annual meetings shall be held at a time most convenient for the majority of the members at a place designated by the executive committee. At this meeting the election of members shall be announced, the proceedings of the preceding meeting be read, all society business transacted, scientific papers read and discussed, and officers for the ensuing year shall be elected.

ARTICLE VI. AMENDMENTS

This constitution may be amended at any time, provided that such amendment is proposed and signed by at least five members of the Association, and is presented and discussed at any annual meeting of the Association. The secretary shall take a ballot of the membership by mail within thirty days after the meeting of the Association, and a majority vote of the ballots received shall be sufficient to amend, provided more than one-half of the members return ballots.

ARTICLE VII. PUBLICATION

The proceedings of the annual meeting and the papers read shall be published in an annual bulletin. This shall be under the immediate supervision of the editor-in-chief, assisted by associate editors whom he shall appoint in the various regions.

ARTICLE VIII. SECTIONS

SECTION 1. Regional sections of the Association may be established provided the members of such sections shall perfect a regional organization and make application to the executive committee, who shall submit the application to a vote at a regular annual meeting, a vote of two-thirds of the members present being necessary for the establishment of such a section; and provided that the Association may revoke the charter of any section by a vote of two-thirds of the membership.

BY-LAWS

SECTION 1. *Dues.*—The regular annual dues of an active member of the Association shall be $15.00. The annual dues of an associate member of the Association shall be $8.00. The annual dues are to be paid to the secretary-treasurer on or about January first for the year ending the following December.

SEC. 2. Any member who shall fail to pay his regular annual dues for a period of one year may be suspended by a vote of the executive committee, but may be reinstated upon the unanimous consent of the committee.

SEC. 3. The payment of the annual dues entitles the member to receive, without further charge, one copy of the proceedings of the Association for that year.

SEC. 4. Any member who shall be guilty of flagrant violation of the established principles of professional ethics may, upon the unanimous vote of the executive committee, be suspended or expelled from membership, provided that such person shall before suspension or expulsion be granted a hearing before the executive committee.

AMENDMENTS

These by-laws may be amended by the vote of three-fourths of the active members present at any annual meeting.

GEOGRAPHIC DISTRIBUTION OF ASSOCIATION MEMBERS

On March 1, 1927, there were 1,670 members of the Association in 39 states and 23 foreign countries, as follows:

UNITED STATES

Texas	476	Massachusetts	8	Alabama	2
Oklahoma	382	Montana	8	Michigan	2
California	210	West Virginia	8	Mississippi	2
Colorado	69	New Mexico	7	Tennessee	2
New York	66	Ohio	7	Virginia	2
Kansas	62	Connecticut	6	Florida	1
Louisiana	56	Minnesota	6	Maine	1
Pennsylvania	42	Iowa	4	Nevada	1
Illinois	20	Maryland	4	North Carolina	1
Washington, D.C.	20	Washington	4	Oregon	1
Arkansas	14	Nebraska	3	South Dakota	1
Missouri	12	New Jersey	3		
Wyoming	12	Utah	3	Total United States	1,540
Kentucky	9	Wisconsin	3		

FOREIGN

Mexico	31	France	3	Burma	1
Venezuela	28	Peru	3	Germany	1
England	11	Roumania	3	Java	1
Canada	9	Switzerland	3	Sumatra	1
Argentina	8	Borneo	2	U.S. Soviet Republics	1
Colombia	6	Australia	1		
Holland	6	Belgium	1	Total Foreign...	130
Japan	4	Bolivia	1		
Trinidad	4	British Guiana	1		

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS MEMBERSHIP LIST

March 1, 1927

HONORARY MEMBERS

The executive committee may from time to time elect as honorary members persons who have contributed distinguished service to the cause of petroleum geology. Honorary members shall not be required to pay dues, nor shall they be allowed to vote.—*Sec. 7, Article III, of the Constitution*

Hill, Robert T., Hotel Commodore, Los Angeles, Calif.
Orcutt, W. W., Union Oil Company of Calif., Union Oil Bldg., Los Angeles, Calif.
Smith, George Otis, U. S. Geological Survey, Interior Bldg., Washington, D.C.
White, David, U. S. Geological Survey, Interior Bldg., Washington, D.C.
White, I. C., state geologist, Morgantown, W.Va.

ACTIVE MEMBERS

Any person actively engaged in the work of petroleum geology or in research pertaining to petroleum geology or technology is eligible to active membership in the American Association of Petroleum Geologists, provided he is a graduate of an institution of collegiate standing, in which institution he has done his major work in geology, and in addition has had the equivalent of three years' field experience in petroleum geology; and provided further that in case of an applicant for membership who has not had the required collegiate or university training, but whose standing in the profession is well recognized, he shall be admitted to membership when his application shall have been favorably and unanimously acted upon by the executive committee; and provided further that these requirements shall not be construed to exclude instructors and professors in recognized institutions of learning whose work is of such character as in the opinion of the executive committee shall qualify them for membership.—*Sec. 1, Article III, of the Constitution*

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Any person having completed as much as thirty hours of geology (an hour shall here be interpreted as meaning as much as sixteen recitation or lecture periods of one hour each, or the equivalent in laboratory) in a reputable institution of collegiate or university standing, or who has done field work equivalent to this, shall be eligible to associate membership in the American Association of Petroleum Geologists, provided that at the time of his application for membership he shall be engaged in geological studies in an institution of collegiate or university standing, or shall be engaged in geological work. *Sec. 2.*

Associate members shall enjoy all privileges of membership in the Association, save that they shall not hold office, sign applications for membership, or vote in business meetings; neither shall they have the privilege of advertising their associate membership in the Association in professional cards, nor shall they have the privilege of signing professional reports as associate members of the Association.—*Sec. 4, Article III, of the Constitution*

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Miller, Carroll C., Associated Oil Co., Mirando City, Tex.
Miller, Edward F., Box 1169, Denver, Colo.
Milner, Charles A., Jr., Box 686, Cisco, Tex.
Mitchell, Robert C., Geol. Dept., Waite-Phillips Co., Tulsa, Okla.
Mix, C. A., Box 846, Colorado, Tex.
Mohr, Clifford L., Marland Oil Co. of Texas, San Angelo, Tex.
Moore, Prentiss D., Imperial Oil Co., 56 Church St., Toronto, Ont., Canada
Morero, Joseph E., Box 853, San Angelo, Tex.
Morris, Walter W., Eagle-Pitcher Lead Co., Oil and Gas Dept., Henryetta, Okla.
Morse, Paul F., 203 Neils Esperson Bldg., Houston, Tex.
Moser, Gerald E., Box 379, Bartlesville, Okla.
Mower, Lowell K., Roxana Petroleum Corp., Athletic Club Bldg., Dallas, Tex.
Mulky, Francis P., 201 W. Fourteenth St., Oklahoma City, Okla.
Munson, Herbert E., % Dr. D. O. Munson, Pittsburgh, Kan.

Murphy, Earle N., 117 E. Seventeenth St., Tulsa, Okla.
Myers, Julian Q., 116 E. King St., Tulsa, Okla.

Nelson, Fred M., Humphreys Corporation, Mason Bldg., Houston, Tex.
Nelson, Thomas M., 2600 Maple Ave., Dallas, Tex.
Nessley, Howard E., 1717 W. Mulberry St., San Antonio, Tex.
Newman, Thomas F., Midwest Exploration Co., Abilene, Tex.
Noble, Earl B., Union Oil Co. of California, 514 Union Oil Bldg., Los Angeles, Calif.
Noble, Gilbert W., Box 205, Coffeyville, Kan.
Nolte, Wm. J., Marland Oil Co. of Texas, Box 1428, Wichita Falls, Tex.
Nordman, O. E., Geol. Dept., Box 2044, Tulsa, Okla.

Oakes, Malcolm C., 530 W. Symmes St., Norman, Okla.
Obering, Ernest A., Room 912 Giddens-Lane Bldg., Shreveport, La.
Oborne, Harry W., 2001 N. Cascade Blvd., Colorado Springs, Colo.
O'Brien, Shamus, Florence, Kan.
Oles, L. M., Prairie Oil and Gas Co., Box 263, Tulsa, Okla.
Oles, Paul S., Box 1508, Wichita Falls, Tex.
Osborne, Robert R., University Club, Tulsa, Okla.
Owen, Herman J., 304 N. Third St., Okemah, Okla.
Owens, Frith C., R.F.D. 1, Box 1239, Houston, Tex.
Oyster, Frank A., Box 392, Independence, Kan.

Pack, Oran L., Geol. Dept., Huasteca Petroleum Corp., Tampico, Mexico
Packard, Sidney A., 1200 W. Thirtieth St., Oklahoma City, Okla.
Palmer, R. H., 533 Dexter-Horton Bldg., Seattle, Wash.
Park, Hazel, 613 Johnstone Ave., Bartlesville, Okla.
Parks, Ernest K., 1523 Standard Oil Bldg., San Francisco, Calif.
Paschal, Elisha A., 1011 Tradesman's National Bank Bldg., Oklahoma City, Okla.
Paul, Elmer W., Box 1112, Eldorado, Kan.
Pease, Cecil C., 1261 Buchanan St., Topeka, Kan.
Perry, Samuel S., 601 South Rampert St., Los Angeles, Calif.
Pettigrew, Virgil, Humble Oil & Refining Co., Box 1034, Wichita Falls, Tex.
Philbrick, E. P., 318 Alexander Bldg., Abilene, Tex.
Phillips Eldridge D., Box 790, Lake Charles, La.
Pishney, Charles H., Carter Oil Co., Box 2045, Tulsa, Okla.
Polkinghorn, J. Wilber, Garnett, Kan.
Pollak, Rudolf R., 1712 Second St., Bakersfield, Calif.
Ports, Waldo W., 1823 Collins Ave., Wichita Falls, Tex.
Postley, Olive C., 3600 Sixteenth St., Washington, D.C.
Potter, Nelson B., Box 2046, Tulsa, Okla.
Pratt, Ernest S., Roxana Petroleum Corp., Box 307, Ponca City, Okla.
Price, Earl M., The Associated Oil Co., Oil Center, Calif.
Purzer, Joseph, 1620 W. First St., Tulsa, Okla.
Putnam, Laurence G., Apartado 106, Tampico, Mexico.

Quiett, Roy C., 1310 Wolfe St., Little Rock, Ark.

Ralston, Wallace, 2309 W. Platte St., Colorado Springs, Colo.
Rathwell, Harold B., 4921 Cimarron St., Los Angeles, Calif.
Reed, Lyman C., Rio Bravo Oil Co., 320 Southern Pacific Bldg., Houston, Tex.
Reed, Warren B., Morgan City, La.
Reynolds, Robert E., address unknown

Richards, A. Howard, Marland Refining Co., Geol. Dept., Ponca City, Okla.
Ridgeway, Bertrand S., Box 392, Independence, Kan.
Rife, Byron, Box 1262, Abilene, Tex.
Robbins, C. C., 1710 Union Bank Bldg., Pittsburgh, Pa.
Roberts, Dwight C., 2000 West Twelfth St., Los Angeles, Calif.
Roberts, Louis C., Jr., 1700 Jackson St., Amarillo Tex.
Robertson, Parker A., Apartado 106, Tampico, Mexico
Robinson, B. F., 1736 E. Fourteenth St., Tulsa, Okla.
Rogatz, Henry, Marland Oil Co., Amarillo, Tex.
Rohrbach, G. Lynn, 708 Wright Bldg., Tulsa, Okla.
Roop, Charles W., Drawer L, Bartlesville, Okla.
Roth, Ernest E., 7104 Idlewild St., Pittsburgh, Pa.
Rowland, W. Boyd, Box 18, Trinidad Oil Fields Operating Co., Ltd., Trinidad, B.W.I.
Rubel, Albert C., 105 San Antonio Drive, Long Beach, Calif.
Rusk, Willard W., Box 150, Parco, Wyo.
Russell, J. R., Standard Oil Co. of California, Drawer J, Whittier, Calif.
Rutledge, Richard B., Box 815, Winfield, Kan.
Ryan, Reginald G., Capitol Hotel, Graham, Tex.
Ryan, Russell F., 1238 S. Oak St., Freeport, Ill.
Ryniker, Charles, Box 2044, Tulsa, Okla.

Samuell, J. Howard, Box 652, Coleman, Tex.
Sax, Henri, Bataafsche Petr. Mij., Pangkalan Brandan, Sumatra, D.E.I.
Say, Stanley R., Pan American Exploration Co., 120 Brodway, New York, N.Y.
Schaeffer, Hugh C., Box 288, Abilene, Tex.
Schlosser, Paul A., Box 532, San Angelo, Tex.
Schmidt, Karl A., Box 308, Cisco, Tex.
Schmittou, Maurice B., Apartado 162, Tampico, Mexico
Schneider, G. W., Box 96, Shreveport, La.
Schnurr, Cornelius, 112 Central Bldg., Amarillo, Tex.
Schouten, Franklin H., Marland Oil Co., 504 Central National Bank, San Angelo, Tex.
Schwab, Philip A., Box 146, Dawson Springs, Ky.
Schwarz, Melbert E., 318 Southern Pacific Bldg., Houston, Tex.
Scruggs, Maurice D., Marland Refining Co., Box 1267, Ponca City, Okla.
Seitz, J. R., Billings, Okla.
Severson, George, Apartado 58, Venezuelan Atlantic Refining Co., Caracas, Venezuela, S.A.
Shakley, Ed. G., Box 278, Braman, Okla.
Shamblin, W. E., Box 296, Holdenville, Okla.
Shaw, Silas F., 301 Terrell Road, San Antonio, Tex.
Shelton, T. O'D., Box 206, Santa Anna, Tex.
Shoults, Carl S., Box 78, Toyah, Tex.
Sidwell, Carroll V., Geol. Dept., Huasteca Petr. Co., Apartado 94, Tampico, Mexico
Simpson, Earl, Roxana Petroleum Corp., Ardmore, Okla.
Skirvin, Orren W., American Oil & Refining Co., Box 282, Ada, Okla.
Smiley, H. F., Marland Oil Co. of Texas, San Angelo, Tex.
Smirnoff, Michael A., Roxana Petroleum Corp., Post-Dispatch Bldg., Houston, Tex.
Smith, A. J., Humphreys Corporation, Mason Bldg., Houston, Tex.
Smith, Erwin W., 312 West Bldg., Houston, Tex.
Smith, Gene R., 2104 Magnolia Bldg., Dallas, Tex.
Smith, Merritt B., Tropical Oil Co., Apartado 70, Barranca Bermeja, Cartagena, Colombia, S.A.
Smoots, John P., 407 Jordan St., Shreveport, La.
Solliday, A. L., Dixie Oil Co., 332 Harvey Snider Bldg., Wichita Falls, Tex.

Sorensen, Alfred H., Ord, Neb.
Spangler, Grant W., Box 959, Enid, Okla.
Spice, William H., Jr., Lago Petroleum Corp., Apartado 172, Maracaibo, Venezuela, S.A.
Splane, Howard, Devonian Oil Co., Box 1441, Tulsa, Okla.
Sprague, William B., Box 742, Corsicana, Tex.
Spriggs, Herbert S., 4209 N. Mullen, Tacoma, Wash.
Staggs, Olan B., 802 W. Main St., Enid, Okla.
Stanley, M. Wood, Box 441, Dallas, Tex.
Stastny, Herman R., 1118 Peach St., Abilene, Tex.
Stein, Ira H., Marland Refining Co., Geol. Dept., Ponca City, Okla.
Stephano, Constantine S., 1014–16 Walnut St., Philadelphia, Pa.
Stewart, Charles H., Box 942, Eastland, Tex.
Stilley, Earl M., 2105 Hayes St., Wichita Falls, Tex.
Stipp, Thomas F., % Theo. Chapin, Luisa Martin Bldg., Laredo, Tex.
Striker, Arthur F., Box 626, Nocona, Tex.
Stubbs, John T., Orange Petroleum Corp., Orange, Tex.
Swiger, Rual B., Roxana Petroleum Corp., 22 Clinton Bldg., Abilene, Tex.

Tandy, J. Hiram, R. 1, Box 130, Fifty-first St., Tulsa, Okla.
Tappolet, W., 312 Travis Bldg., San Antonio, Tex.
Taylor, Cyril B., Box 494, Cisco, Tex.
Taylor, Thomas G., Oil Prod. Dept., Empire Gas & Fuel Co., Bartlesville, Okla.
Teas, Paul C., Box 507, Colorado, Tex.
Teets, D. Dee, Jr., 1658 Franklin Ave., Charleston, W.Va.
Tharp, Paul A., 320 E. Eleventh St., Winfield, Kan.
Thomson, B. E., Box 737, Gulf Prod. Co., Fort Worth, Tex.
Thompson, T. C., 807 W., Thirteenth St., Cisco, Tex.
Thompson, Warren O., Geol. Dept., University of Colorado, Boulder, Colo.
Thornburgh, H. R., Box 868, San Angelo, Tex.
Tiedemann, Alex, Box 358, Brownsville, Tex.
Tillotson, Harold H., Latham, Kan.
Toler, Henry N., 294 Natural History Bldg., University of Illinois, Urbana, Ill.
Tollefson, E. H., Roxana Petroleum Corp., Waggoner Bldg., Wichita Falls, Tex.
Torrey, Paul, Northwestern Pennsylvania Producers Assoc., Bradford, Pa.
Trainer, David W., Jr., 218 Wait Ave., Ithaca, N.Y.
Travis, Raymond G., Cia. Minera Choc6 Pacifico, Andagoya, via Buenaventura, Colombia, S.A.
Tucker, Merwin B., 815 Wright Bldg., Tulsa, Okla.
Tweedy, Joseph L., Knickerbocker, Tex.
Tygrett, H. V., 702 Magnolia Bldg., Dallas, Tex.
Tyson, Alfred K., Maysfield, Tex.

Valerius, Claude N., Wilcox Bldg., Tulsa, Okla.
Van Dall, John E., Box 518, Covington, Okla.
Vanderpool, Harold C., Box 1096, Shreveport, La.
Van Weelden, Arie, Roxana Petroleum Corp., Athletic Club Bldg., Dallas, Tex.
Van Zant, James H., 429 W. Twenty-fourth St., Oklahoma City, Okla.
Vernon, Jess, Box 896, Shawnee, Okla.
Vertrees, Charles D., 1621 W. Beauregard St., San Angelo, Tex.
Vorbe, Georges, Thurber, Tex.

Waldo, Kenneth C., 952 Colbert Ave., Oil City, Pa.
Walker, A. Wellesley, % Grubstakers, Rolla, Mo.
Waring, John D., Jr., City Engineer, Comanche, Tex.

Waterfall, Louis N., Union Oil Co. of Calif., Union Oil Bldg., Los Angeles, Calif.
Waters, James A., The Sun Co., American Exchange National Bank Bldg., Dallas, Tex.
Watkins, Walter G., 32 Second St., Rankin, Pa.
Watkins, William A., Edificio Banco Boston 713, Buenos Aires, Argentina, S.A.
Watson, Cresap P., 65 Broadway, Amerada Corporation, New York, N.Y.
Watson, Joseph D., 2543 E. Eleventh St., Tulsa, Okla.
Weaver, Donald K., 141 Brookdale Ave., Fullerton, Calif.
Weaver, George A., Pure Oil Co., Box 657, Mexia, Tex.
Webster, Hugh B., Standard Oil Co., Standard Oil Bldg., San Francisco, Calif.
Weed, William F., Box 12, Laredo, Tex.
Weeks, Herbert J., Sun Oil Co., Box 1109, Dallas, Tex.
Weisbord, Norman E., Consulado Americano, Barranquilla, Colombia, S.A.
Wender, W. G., Box 746, Forth Worth, Tex.
Wendlandt, Edward A., Box 1034, Wichita Falls, Tex.
West, Joe W., Apartado 234, Venezuelan Gulf Oil Co., Maracaibo, Venezuela, S.A.
Whealton, Rowland G., Box 3348, Taft, Calif.
Wheeler, Carlton W., Box 248, Coleman, Tex.
Wheeler, Holmes Cubbage, Healdton Oil and Gas Co., Enid, Okla.
Whitcomb, Bruce, 1806 F. and M. Bldg., Fort Worth, Tex.
White, Maynard P., 460 W. Hundred Forty-fourth St., New York, N.Y.
White, Stanley B., Box E, Burlington, Kan.
Whiteside, C. Edwin, Marland Oil Co., A. G. Bartlett Bldg., Los Angeles, Calif.
Whitney, Paul A., Box 2024, Mid-Continent Petroleum Corp., Tulsa, Okla.
Whitwell, Elvis B., 216 E. Tonhawa St., Norman, Okla.
Whitworth, Virgil L., Simms Oil Co., Magnolia Bldg., Dallas, Tex.
Wiest, Frank C., Crusader Pipe Line Co., Shreveport, La.
Williams, Francis S., W. C. McBride, Inc., Woodsfield, Ohio.
Williams, Garnett A., Burke Greis Oil Co., Box 262, Tulsa, Okla.
Williamson, Thomas S., 569 Boulevard, Norman, Okla.
Wilshire, L. M., Box 103, Holdenville, Okla.
Wilson, John H., Apartado 94, Huasteca Petroleum Corp., Tampico, Mexico
Wilson, Leslie E., Golden, Colo.
Witherspoon, Gavin, Jr., Box 1200, Bakersfield, Calif.
Wolf, Albert G., Texas Gulf Sulphur Co., 1510 Second National Bank Bldg., Houston, Tex.
Wood, Fred E., Midwest Refining Co., Casper, Wyo.
Woods, E. Hazen, Atlantic Oil Producing Co., Box 1037, Wichita Falls, Tex.
Woods, Rolland H., Box 511, Laredo, Tex.
Word, Ernest B., Box 518, Covington, Okla.
Wosk, L. David, 1231 S. Boulder St., Tulsa, Okla.
Wuensch, C. Erb, % A. J. McAllister, 100 Broadway, New York, N.Y.
Wylie, James R., Jr., 505 Frick Bldg., Pittsburgh, Pa.
Wyman, Everett A., Box 2022, Amerada Corporation, Tulsa, Okla.
Wynn, Warren H., Prairie Oil and Gas Co., Box 263, Tulsa, Okla.

Yeager, Lloyd I., Empire Companies, Geol. Dept., Bartlesville, Okla.
Young, Claude T., Box 788, Oxford, Kan.
Young, Karl Etienne, Rycade Oil Corp., Houston, Tex.

Zaba, Joseph, address unknown
Zavoico, Basil B., 342 Masonic Bldg., Enid, Okla.
Zoller, Henry E., Box 278, Braman, Okla.
Zorichak, Joseph J., 504 Milton Ave., Casper, Wyo.

AT HOME AND ABROAD

W. IRWIN MOYER spent the winter in Switzerland.

O. M. EDWARDS, of the Red Bank Oil Company, has returned from San Angelo, Texas, to Tulsa, Oklahoma.

RALPH E. DAVIS, of Pittsburgh, took a trip to Jamaica in February.

E. RUSSELL LLOYD is in charge of the geological work of the Roxana Petroleum Corporation at Roswell, New Mexico.

JOSEPH M. WILSON, chief geologist of the Simms Oil Company of Dallas, is a frequent visitor at San Angelo.

GEORGE SAWTELLE, manager of the Kirby Oil Company, has moved from Houston to San Angelo.

MISS H. T. KNIKER resigned from the El Capitan Oil Company of San Angelo, January 31.

E. S. MCLAUGHLIN is geologist for Geo. A. Henshaw, Jr., Company of San Angelo, Texas.

O. B. STAGGS, of the Atlantic Refining Company at Maracaibo, spent January at Enid, Oklahoma, on a vacation.

J. C. TEMPLETON has resigned from the Humble Oil & Refining Company and has gone to Mexico.

H. H. HENDERSON, of San Angelo, Texas, has resigned from the El Capitan Oil Company to accept a position with the Tidal Oil Company.

ROBERT BURNS CAMPBELL is engaged in consulting work at San Angelo, Texas.

EMIL OTT is consulting geologist at San Angelo, Texas.

M. C. LUCKY represents the Houston Oil Company at San Angelo, Texas.

FLOYD O. REYNOLDS died January 31 at San Angelo, Texas. He was employed by the Amerada Petroleum Corporation during the two preceding months. Prior to that time he worked for the Indian Territory Illuminating Oil Company in Kansas, Colorado, and New Mexico. During the past two years he has suffered from tuberculosis contracted as a result of gassing in the World War. He is survived by his widow.

CHARLES R. ECKES has skimmed oil off Smackover Creek, Smackover, for the past two years with great success. How about trying Lake Maracaibo next, Charlie?

J. H. DURDEN is chief geologist of the Indian Territory Illuminating Oil Company of Bartlesville.

PAUL APPLIN and A. E. FATH have reported on the new oil seepage at Key West, Florida.

JOHN F. WEINZIERL is engaged as consulting geologist in Houston.

DJEVAD EYOUB has been in Mexico two months for the Henry L. Doherty interests. Mr. Eyoub's address is Luisa Martin Building, Laredo, Texas.

VICTOR J. HENDRICKSON, formerly with the Midwest Refining Company, is now with the California Petroleum Corporation at Sunburst, Montana.

GEORGE STEINER, geophysical surveys, has transferred his office to 330 Post-Dispatch Building, Houston, Texas.

CLAUDE N. VALERIUS is geologist for the Phillips Petroleum Corporation at San Angelo, Texas.

The North Texas Geological Society of Wichita Falls, Texas, elected the following officers for the year: president, C. W. CLARK; vice-president, F. C. SEELEY; secretary-treasurer, ARCHIE KAUTZ. The members of the society entertained their wives and friends with a dinner and dance on the evening of January 22, at the Wichita Falls Municipal Golf Club. About one hundred people were in attendance.

J. H. JENKINS, vice-president of the Tidal Oil Company at Fort Worth, visited California in February.

C. T. HARES, chief geologist of the Ohio-Mexican Oil Corporation, has on his staff WILLIAM G. KANE, HERBERT GAYLOR, LEO V. HORTON, STANLEY A. EDDINS, CHESTER A. HAMMILL, and FOREST HOOD. Their headquarters are at Cuatro Cienegas, Coahuila, Mexico.

CHESTER A. REEDS, of the American Museum of Natural History, New York City, published "The Arbuckle Mountains, Oklahoma," in *Natural History*, N.Y., Vol. 26 (1926), pp. 462–74. He described a new formation, the Frisco limestone, at the top of the Hunton group.

PAUL OLES is geologist for the Prairie Oil and Gas Company at Wichita Falls, Texas.

R. ZUMELZU published an article on petroleum in Bolivia ("El petróleo en Bolivia") in *Revista Minera de Bolivia*, Oruro, Bolivia, 1926.

Word has been received of the death in Nice, France, of E. T. DUMBLE, who was a prominent figure in the early days of geology in the southwest. Mr. Dumble was an honorary member of this Association.

At a meeting of the FORT WORTH GEOLOGICAL SOCIETY, January 22, the following officers were elected for the new year: J. ELMER THOMAS, president; ROBERT S. BURG, vice-president; WALTER R. BERGER, secretary-treasurer (re-elected); F. B. PLUMMER, J. EARLE BROWN, and R. S. BURG, program committee.

CHARLES S. SCHUCHERT, emeritus professor of paleontology at Yale University, stopped off at Shreveport for several days on his way to California and delivered two lectures under the auspices of the Shreveport Geological Society. Dr. Schuchert spoke on the paleogeography of parts of Texas, Arkansas, and Louisiana at the first meeting, and later he discussed the Wegener displacement theory. Dr. Schuchert spent part of the winter in California.

MERLE C. ISRAELSKY, paleontologist with the Standard Oil Company of Louisiana at Shreveport, has accepted a position with the Palmer Corporation at Shreveport.

E. B. HUTSON, paleontologist with the Humble Oil & Refining Company at Shreveport, has accepted a position as paleontologist with the Standard Oil Company of Louisiana at Shreveport.

C. L. MOODY, geologist for the Ohio Oil Company at Shreveport, has discovered what may be a new salt dome in Sec. 23, T. 13 N., R. 6 W., Natchitoches Parish, Louisi-

ana. A well has been drilled here on the basis of surface geology, and the Nacotoch sand found more than 600 feet higher than normal.

E. H. FINCH will succeed NILES WINTER as division geologist for the Atlantic Oil Producing Company at Shreveport. Mr. Winter will go to West Texas for his company.

H. J. WEEKS represents the Sun Company at Shreveport.

JOHN H. STINSON, lately graduated from the Louisiana State University Department of Geology, has accepted a position with the Mineral Division, Louisiana Department of Conservation at Shreveport.

PAUL WEAVER, of the Houston office of the Gulf Production Company, was a recent visitor in Shreveport.

R. T. HAZZARD is now at Shreveport and may be reached at the offices of the Gulf Refining Company there.

MARION H. FUNK, of the geological department of the Louisiana Oil Refining Corporation, returned to Shreveport after several months work in Texas for his company.

SIDNEY POWERS, consulting geologist with the Amerada Petroleum Corporation at Tulsa, visited Wisconsin, New York, California, Texas, and other states last December and January.

J. ELMER THOMAS and ROY A. REYNOLDS opened a new pool in Eastland County, Texas, January 17.

C. O. DOUB, of Cisco, Texas, is associated with A. T. Wright.

A. A. HAMMER is geologist for the Hurley Gasoline Company, at Abilene, Texas.

E. W. AMES, of Cisco, Texas, is representing Winston P. Henry *et al.* of Tulsa.

JAMES B. TEMPLETON is geologist for the Sunray Oil Company of Tulsa.

C. W. BYRON has resigned from the Amerada Petroleum Corporation to accept a position with the Margay Oil Corporation of Tulsa.

EDWIN H. HUNT, for several years associated with Irvine E. Stewart, consulting geologist, returned to the United States last summer, after spending fifteen months in New Zealand, and is now district geologist for the California Petroleum Corporation, Salt Lake City, Utah.

ELFRED BECK is now chief geologist for the Producers & Refiners Corporation, with headquarters at Parco, Wyoming.

FRED S. WRIGHT, geologist with the California, is in Denver following several months' geological work in southeastern Utah and northern Arizona.

C. J. HARES, chief geologist of the Ohio Oil Company, spent Christmas at Denver. Mr. Hares is conducting a geological investigation in Coahuila, Mexico.

W. VAN HOLST PELLEKAAN, of the Roxana Petroleum Corporation, spent part of the winter in Europe on business.

EVERETTE LEE DEGOLYER, president of the Amerada Corporation, left for London in March on a business trip.

C. P. BUTCHER is geologist for the Republic Production Company at San Angelo, Texas.

R. B. PAXSON has resigned from the Humphreys Corporation and joined the Atlantic Oil Producing Company.

RUDOLPH BRAÜCHLI has moved to San Angelo, Texas.

C. E. COOK has resigned from the United North and South Oil Company of Luling, Texas.

W. R. CALVERT is living at Del Rio, Texas.

JOSEPH H. SINCLAIR can be reached, care W. G. Bedard, 40 Lakeside Ave., Ottawa, Canada. He returned to New York from Europe in January.

RODERIC CRANDALL has an office at 17 Battery Place, New York City.

A. G. MADDREN is geologist for the Houston Gulf Gas Company of Houston.

JOHN L. FERGUSON resigned from the Borealis Oil Company in January to accept a position with the Amerada Petroleum Corporation at Amarillo, Texas.

P. B. KING is attending the University of Texas.

H. J. MORGAN, of Ebano, Mexico, visited Texas in January.

The ARDMORE GEOLOGICAL SOCIETY met Saturday, January 15, and elected officers for 1927 as follows: SAM WOODS, president; C. W. TOMLINSON, vice-president; GEO. E. BURTON, secretary-treasurer. These replace the officers of 1926, who were: Geo. E. Burton, president; Sam Woods, vice-president; Ralph A. Birk, secretary-treasurer.

D. R. SEMMES, 25 Broadway, New York, left the middle of January for Colombia. Mr. Semmes has been located in Cisco, Texas, during the past few months and will return there upon his return to the States in the middle of March.

JOHN B. KERR, petroleum geologist, 601 Balboa Building, San Francisco, California, returned last January from an extended trip to the Mid-Continent district where he was engaged about two months in exploration for oil and gas in Kentucky. Mr. Kerr was also busy in Southern California in January.

The Mid-Continent section of the AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS (FRANK A. HERALD, chairman), meeting at Tulsa, Oklahoma, January 15, elected the following officers for 1927: chairman, A. W. AMBROSE; vice-charmen, CHARLES V. MILLIKAN, H. C. GEORGE, C. C. OSBORN; secretary-treasurer, BURR McWHIRT; executive committee, E. P. CAMPBELL, ALFRED G. HEGGEM, A. I. LEVORSEN, and J. O. LEWIS; program committee, CHARLES V. MILLIKAN, GEORGE S. ROLLIN, and ALLAN F. HINTON.

MARVIN LEE and J. L. GARLOUGH have moved their consulting offices from the Masonic Temple Building to 612, 615, 616 Brown Building, Wichita, Kansas, effective March 1. The move was made to secure more space.

D. E. LOUNSBERY has resigned from the Midwest Exploration Company to accept a position with the Phillips Petroleum Company at Fort Worth.

The PANHANDLE GEOLOGICAL SOCIETY met at Amarillo, Texas, December 17, 1926, and listened to a paper by TED CRUM on "The Geology of that Part of Utah Between the San Rafael Swell and Colorado River." The paper was well illustrated with maps, cross sections, and photographs. On January 7, 1927, the society had another very interesting meeting to discuss water in the Panhandle field. About fifty operators, geologists, and engineers were present. RONALD K. DEFORD gave a paper on "The Chemistry of the Hutchinson Field Waters." N. O. MILLER gave a paper on "Methods of Combating the Encroachment of Water." After a very lively discussion by many of those present, the general conclusions reached were that the conservation of gas is one of the most important

items in combating the encroachment of water in the producing wells. It was brought out also that the water is essentially bottom-water and that wells producing a large amount of gas with the oil have caused the greatest amount of water encroachment. It was decided that excessive swabbing caused the coming in of water under the well.

MRS. HELEN JEANNE PLUMMER has completed a very full report on the foraminifera of the Midway formation of Texas, which is being published by the Bureau of Economic Geology of the University of Texas.